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Eco-friendly mortars with granite powder and fly ash and their prediction with artificial neural networks

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Abstract

This paper focuses on mortar in which cement is partially replaced with siliceous fly ash and granite powder and subjected to abrasion. To optimise the process of testing abrasion resistance, artificial neural network (ANN) was proposed to predict results. Predicting abrasion resistance of mortar, especially with addition of wastes is not widely explored and requires greater academic attention. The possibility of applying machine learning is reducing amount of destructive tests methods in favour of prediction, therefore sustainable approach. This study confirms that it is possible to create eco-friendly mortar with siliceous fly ash and / or granite powder and that these materials do not deteriorate the surface of mortar samples. The most similar results of abrasion resistance to reference samples with only Portland cement were obtained for combination of fly ash and granite powder. The application of ANN to predict abrasion resistance of tested mortars showed very accurate results with the network's worst quality at 0.967 (with 1.0 as ideal result). The quality of the network relies on properly selected and detailed inputs. This study proved satisfactory results of predicting abrasion resistance based on mortar's components only.

Keywords: mortar, eco-friendly, granite powder, fly ash, cement replacement, machine learning, artificial neural network

1 Introduction

Today more and more people are interested in factors aiming at making construction materials more eco-friendly, as written by Waghmode et. al [1]. Cementitious composites are the most widely used materials in the industry and so there is no surprise many efforts have been undertaken in researches for minimizing their impacts to the environment, described by Wang & Li [2]. It is estimated, that the cement production is responsible for 7% of global emissions of carbon dioxide see Fennell, et. al. [3]. Reducing the content of cement in the mix can potentially minimize source of carbon dioxide atmospheric emissions from power plants.

This study focuses on mortar subjected to abrasion - composite material, consisting of small size aggregates and a binder (mixture of a hydraulic cement and water). One way of reducing cement is its replacement with fly ash. Fly ash is obtained in a high-temperature process and commonly used as main constituents of cement and/or as concrete components see Giereczny [4]. Recycling fly ash for the replacement of cement results in more eco-friendly material. Even though fly ash is a waste, it can be beneficial for mortar parameters to some percentage of replacement (usually up to 30%), decreasing the shrinkage and increasing its resistance to chloride ion penetration, improve fluidity, consistency according to Wankhedem& Fulari [5]. Higher fly ash contents is usually not used as its quality is very variable and converting unreactive fly ash into reactive material by adjusting the chemistry is unlikely to be economically viable see Scrivener [6]. Another possibility of replacing cement is granite powder - waste material from the granite polishing industry. In accordance to the literature survey, there is a huge potential of the granite powder as a replacement of natural fine aggregate. Similarly to fly ash, up to 30% of replacement, granite powder can contribute favourably to concrete without adversely affecting the strength and durability see Ghannam et. al. [7]. Replacement higher than 30% caused a strength decrease according to Vijayalakshmi & Sekar [8].

The abrasion resistance of mortar depends on paste hardness, aggregate hardness, aggregate/paste bond, compressive strength, but also curing and surface finishing techniques as described by Cao et. al. [9]. Mortars with satisfactory abrasion resistance can be used in design of surfaces subjected to loads and moving objects proven by Pranav et. al. [10]. Literature survey points out that there are already researchers on concrete with fly ash see Atis [11] and Gencel et. al. [12] and/or granite powder see Amani et. al. [13] and Singh et. al. [14] and its abrasion resistance. Unfortunately mortars with such replacements are not fully examined pointed out by Czarnecki et. al. [15]. Also granite waste is more often used as coarse or fine aggregate replacement see Sharma et. al. [16] and Amani et. al. [13] and not in the form of powder to replace cement highlighted by Chajec [17] and Mashaly et. al. [18].

Finally having more eco-friendly material tested for abrasion resistance, one has to still perform necessary and time-consuming tests, including damaging samples surfaces. Applying Artificial Intelligence (AI) could optimize the process of testing reported by Abioye et. al. [19]. One of the possibilities is Artificial Neural Network (ANN), already implemented over the years for predicting various properties of cementitious composites see Ahmed et. al. [20]. However, predicting abrasion resistance of mortar and other cementitious composites is not widely explored and requires greater academic attention highlighted by Malazdrewicz & Sadowski [21] [22] and Czarnecki et. al. [15]. Reducing amount of destructive tests methods in favour of prediction and therefore sustainable approach should be studied deeply and more complex.

Summarising, the aim of the article is to introduce mortar in which cement is partially replaced with granite powder and/or fly ash, thus proposing more eco-friendly construction material. Modelling the behaviour in terms of abrasion resistance is strengthened by implementing machine learning algorithms, mainly ANN.

2 Methods

2.1 Preparing samples and abrasion resistance test

Mortar samples were prepared with siliceous fly ash and/or granite powder waste from 0 to 30 % of cement replacement. Water / Binder ratio (W/B) was kept 0.5 for all samples. Variables included content of cement, fly ash, granite powder and Cement / Water ration (W/C) with constant content of water, binder, sand and W/B. In total 11 series were prepared with two samples each (Figure 1). Samples were prepared to tests according to Figure 2.

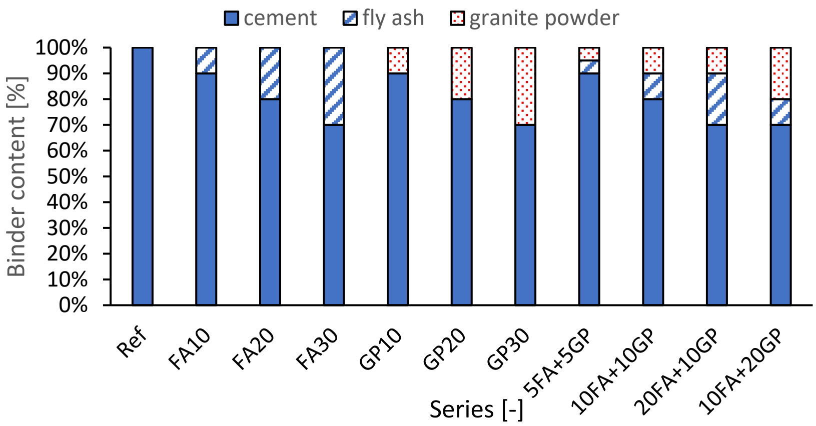


Figure 1: Binder composition for 11 series

Hardened cementitious mortars were subjected to abrasion resistance test using Bőhme method described in standard PN-EN 13892-3. The essence of the test is measuring the change in height and weight of a cubic sample which surface is pressed on to a rotating steel plate using a constant load see Yetgin & Çavdar [23]. For the initial abrasion 4 cycles with 22 rounds were performed and samples were weighed. Next 4 stages of the test were performed, consisting in abrasion resistance evaluation after 4, 8, 12 and 16 cycles of 22 rounds each. After every stage, samples were weighed and measured.

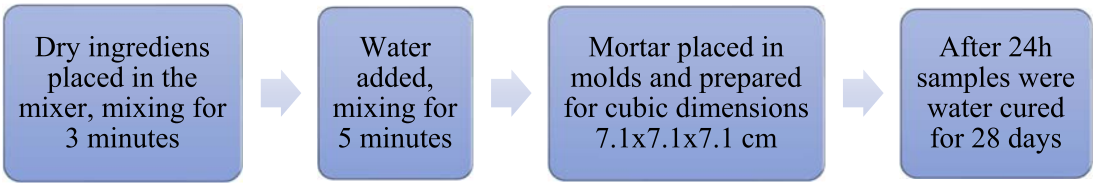


Figure 2: Preparation of samples

2.2 Modelling abrasion resistance with ANN

Current methods of determining abrasion resistance share similar disadvantages, including damaging samples surfaces and time-consuming testing see Xu et. al. [24] and Gupta et. al. [25]. The possible transformation of some tests into prediction methods and therefore the optimization can be achieved by the ANN see Lau [26]. Created ANN was based on selected mortar components with the cycles of testing and mass of a sample after drying. The output was assumed as the depth of wear. Water and sand were omitted as the content for all samples stays the same. The total database consisted of 88 cases. Selected cases are presented in Table 1. Structure of the network is presented in Table 2.

Case no [-]	Cement [-]	Fly ash [-]	Granite Powder [-]	Test cycle [-]	Mass of sample [g]	Depth of wear [mm]
1	1	0	0	4	356,56	0,79
16	0,9	0,05	0,05	4	380,16	1,08
28	0,8	0,2	0	4	370,63	3
42	0,7	0,2	0,1	8	375,29	2,00
50	0,8	0,2	0	12	370,63	2,54
61	0,9	0,05	0,05	12	349,80	2,62
88	0,5	0,1	0,2	16	354,42	4,47

Table 1: Selected cases for creating 88 cases database

Number of inputs	Number of hidden layers	Number of hidden neurons	Activation functions	Learning algorithms
1 to 6	1	1 to 20	Linear, Sinus, Tanh, Logistic, Exponential	Quasi-Newton, Levenberg-Marquardt, Conjugate Gradient

Table 2: Proposed structure of the network

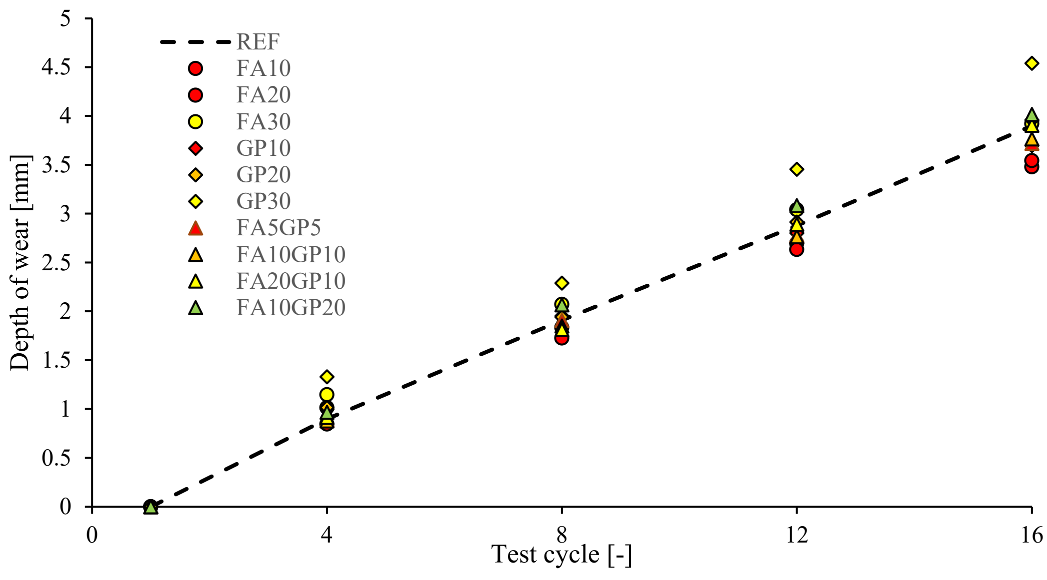
3 Results and analysis

3.1 Depth of wear using standard methods

Figure 3 presents results of abrasion resistance using Bőhme method. Figure 3a presents average depth of wear (of two samples for each series) and Figure 3b average mass loss of sample, both in function of test cycle for 4, 8, 12 and 16.

The results were based on the loss of two parameters, sample weight and height. With every next cycle, depth of wear increases and mass of the sample is decreased. Figure 3a and 3b present the conclusion, that fly ash content (circles) contributed to the lesser depth of wear in some cases. Siliceous fly ash with granite powder (triangles), both up to 20% of binder mass gives promising results, similar to the reference mix. Samples containing only granite powder (diamond) as the cement replacement showed the worst results with both the greatest depth of wear and mass loss. Combination of wastes presented results closer to reference mortar and surely better than just granite powder. The difference in the loss of mass and the depth of wear between mixes with only fly ash and the reference one is small and satisfactory. However, application of fly ash together with granite powder for all configurations gave results the closest to samples based on Portland cement.

a)



3.2. Depth of wear predicted with ANN

The results (Figure 4) were presented using automatic network parameters adjustment. Despite the lack of manual optimization and with a fairly small database, the prediction results are satisfactory and there was no need for further improvement of the network. The linear coefficient R represents the quality of the network and as seen from the graphs it has not dropped below 0.96 [-] (where 1.0 is ideal). The results confirm that for mortars with partial replacement of cement with fly ash and / or granite powder applying ANN results in satisfactory accuracy.

b

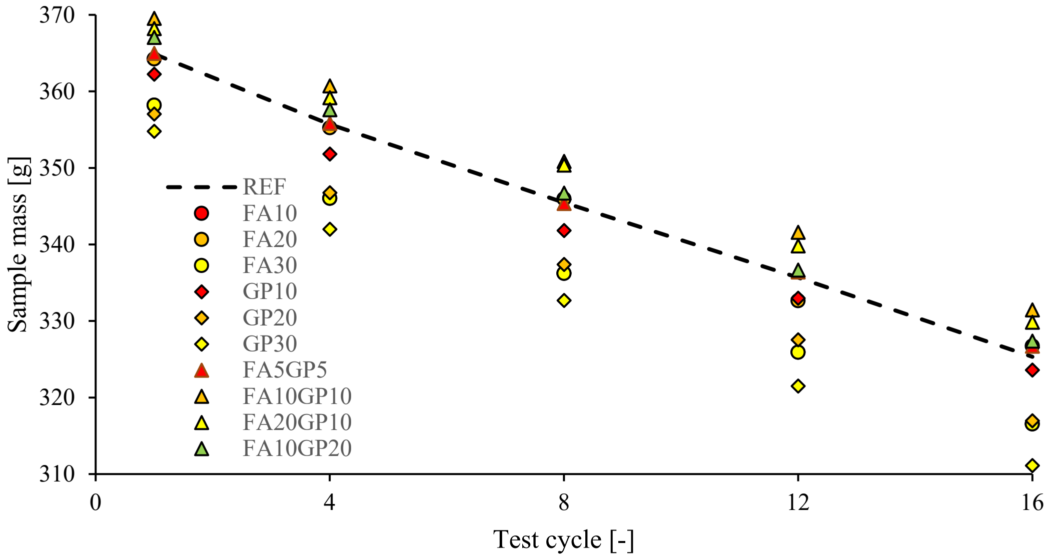


Figure 3: Results of measurements: a) depth of wear b) loss of mass

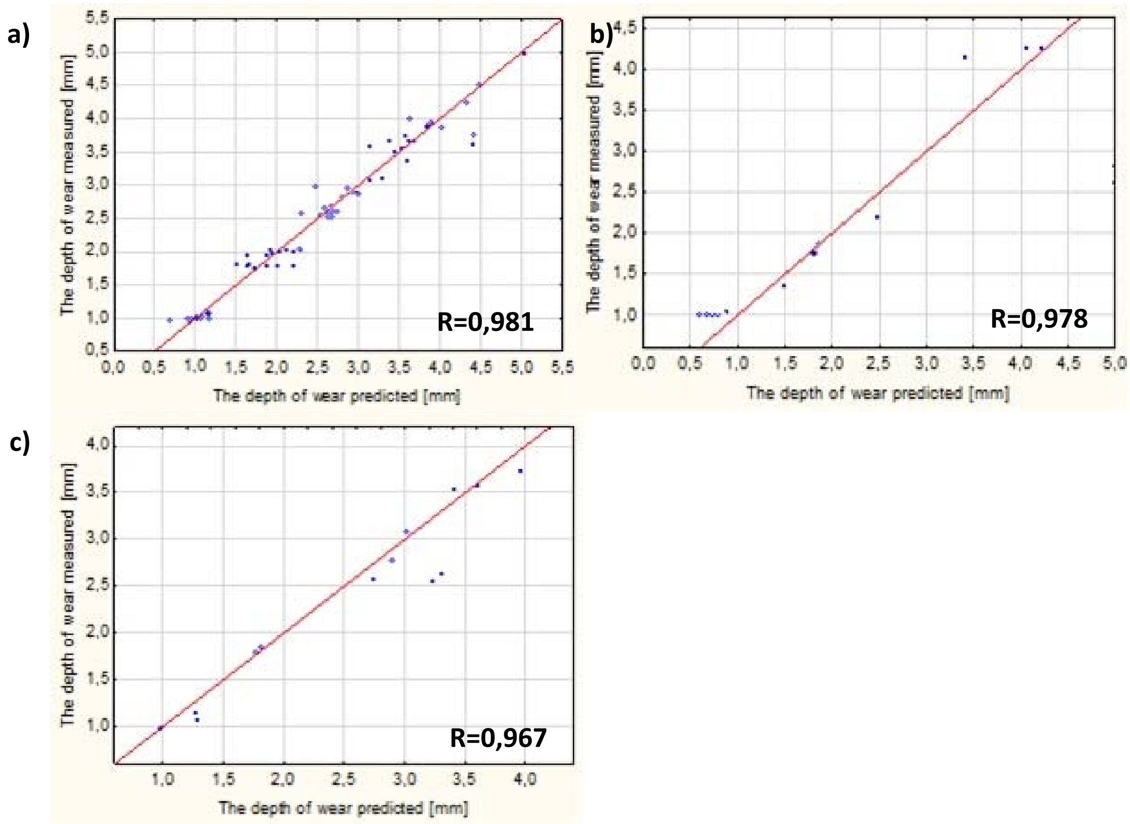


Figure 4: Results of prediction of depth of wear: a) learning b) test c) validation set

4 Conclusions and Contributions

The study confirms that it is possible to create eco-friendly mortar with siliceous fly ash and / or granite powder and that these materials do not deteriorate the surface of mortar samples. The most similar results of abrasion resistance to reference samples with only Portland cement as the binder were obtained for combination of fly ash and granite powder. Granite powder alone showed both the greatest depth of wear and mass loss for each test cycle. Furthermore, the application of AI – namely ANN to predict abrasion resistance of such mortars showed very accurate results with the network's worst quality at 0.967 compared to performed tests. The quality of the network relies on properly selected and detailed inputs. This study proved satisfactory results of predicting based on mortar's components only. The positive impacts of applying such solution include time and cost savings, determination of abrasion resistance based only on composition of the mix without damaging samples. However, abrasion resistance of mortar depends also on factors not analysed in the study: paste and aggregate hardness, aggregate/paste bond, compressive strength, but also human factor and quality of works such as curing and surface finishing techniques.

Thus, this study presents further possibilities of eco-friendly materials aided with machine learning. Further researches might implement other mineral materials suitable as cement replacement, applying different machine learning tool or to expand the inputs with non-destructive tests, minimising human factor after preparing the mix. These solutions can bring us to reduction of carbon footprint, therefore more sustainable construction materials.

References

[1] M. S. Waghmode, A. B. Gunjal, N. N. Bhujbal, N. N. Patil, & N. N. Nawani, "Eco-friendly construction", Reusable and Sustainable Building Materials in Modern Architecture, 80-92, 2019.

[2] S.Wang, & V. C. Li, "Engineered cementitious composites with high-volume fly ash", ACI Materials journal, 104(3), 233, 2007.

[3] P. S. Fennell, S. J. Davis, & A. Mohammed, "Decarbonizing cement production", Joule, 5(6), 1305-1311, 2021.

[4] Z. Giergiczny, "Fly ash and slag", Cement and Concrete Research, 124, 105826, 2019.

[5] P. R. Wankhede, & V. A. Fulari, V. A, "Effect of fly ash on properties of concrete", International Journal of Emerging Technology and Advanced Engineering, 4(7), 284-289, 2014

[6] U. N. Environment, K. L. Scrivener, V. M. John, & E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry", Cement and concrete Research, 114, 2-26, 2018.

[7] S. Ghannam, H. Najm, & R. Vasconez, "Experimental study of concrete made with granite and iron powders as partial replacement of sand", Sustainable Materials and Technologies, 9, 1-9, 2016.

[8] M. Vijayalakshmi, & A. S. S. Sekar, "Strength and durability properties of concrete made with granite industry waste", Construction and Building Materials, 46, 1-7, 2013.
[9] M. Cao, Z. Liu, & C. Xie, "Effectiveness of calcium carbonate whiskers in mortar for improving the abrasion resistance", Construction and Building Materials, 295, 123583, 2021.
[10] S. Pranav, S. Aggarwal, E. H. Yang, A. K. Sarkar, A. P. Singh, & M. Lahoti, "Alternative materials for wearing course of concrete pavements: A critical review", Construction and Building Materials, 236, 117609, 2020.
[11] C. D. Atiş, "High volume fly ash abrasion resistant concrete", Journal of Materials in Civil Engineering, 14(3), 274-277, 2002.
[12] O. Gencel, F. Koksal, C. Ozel, & W. Brostow, "Combined effects of fly ash and waste ferrochromium on properties of concrete", Construction and Building Materials, 29, 633-640, 2012.
[13] A. Amani, A. Babazadeh, A. Sabohanian, & A. Khalilianpoor, "Mechanical properties of concrete pavements containing combinations of waste marble and granite powders", International Journal of Pavement Engineering, 22(12), 1531-1540, 2021.
[14] S. Singh, R. Nagar, V. Agrawal, A. Rana, & A. Tiwari, "Sustainable utilization of granite cutting waste in high strength concrete", Journal of Cleaner Production, 116, 223-235, 2016.
[15] S. Czarnecki, A. Chajec, S. Malazdrewicz, & L. Sadowski, "The Prediction of Abrasion Resistance of Mortars Modified with Granite Powder and Fly Ash Using Artificial Neural Networks", Applied Sciences, 13(6), 4011, 2023.
[16] N. K. Sharma, P. Kumar, S. Kumar, B. S. Thomas, & R. C. Gupta, "Properties of concrete containing polished granite waste as partial substitution of coarse aggregate", Construction and Building Materials, 151, 158-163, 2017.
[17] A. Chajec, "Granite powder vs. fly ash for the sustainable production of air-cured cementitious mortars", Materials, 14(5), 1208, 2021.
[18] A. O. Mashaly, B. N. Shalaby, & M. A. Rashwan, "Performance of mortar and concrete incorporating granite sludge as cement replacement", Construction and Building Materials, 169, 800-818, 2018.
[19] S. O. Abioye, L. O. Oyedele, L. Akanbi, A. Ajayi, J. M. D. Delgado, M. Bilal & A. Ahmed, "Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges", Journal of Building Engineering, 44, 103299, 2021.
[20] M. Ahmed, S. AlQadhi, J. Mallick, N. B. Kahla, H. A. Le, C. K. Singh, & H. T. Hang, "Artificial Neural Networks for Sustainable Development of the Construction Industry", Sustainability, 14(22), 14738, 2022.
[21] S. Malazdrewicz, & Ł. Sadowski, "An intelligent model for the prediction of the depth of the wear of cementitious composite modified with high-calcium fly ash", Composite Structures, 259, 113234, 2021.
[22] S. Malazdrewicz, & Ł. Sadowski, "Neural modelling of the depth of wear determined using the rotating-cutter method for concrete with a high volume of high-calcium fly ash", Wear, 477, 203791, 2021.

[23] Ş. Yetgin, & A. Çavdar, "Abrasion resistance of cement mortar with different pozzolanic compositions and matrices", Journal of Materials in Civil Engineering, 23(2), 138-145, 2011.
[24] F. Xu, M. Zhou, B. Li, & W. Shen, "Influences of polypropylene fiber and SBR polymer latex on abrasion resistance of cement mortar", Journal of Wuhan University of Technology-Mater. Sci. Ed., 25, 624-627, 2010.
[25] M. Gupta, & M. Kumar, "Effect of nano silica and coir fiber on compressive strength and abrasion resistance of concrete", Construction and Building Materials, 226, 44-50, 2019.
[26] C. K. Lau, H. Lee, V. Vimonsatit, W. Y. Huen, & P. Chindaprasirt, "Abrasion resistance behaviour of fly ash based geopolymer using nanoindentation and artificial neural network", Construction and Building Materials, 212, 635-644, 2019.