Surface treatments of recycled brick aggregate and their influence on selected properties of concrete

J Junak, A Sicakova and N Junakova

Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, Kosice 04200, Slovakia

Abstract. The paper is devoted to surface treatment of recycled brick aggregate with various impregnating substances in order to reduce its absorbency and verify the use of such treated recycled material as a partial replacement of natural aggregate (fraction 4/8) in concrete. Selected properties of the tested samples were monitored after 28 and 60 days of curing. The results show that the treatment of recycled bricks with water glass appears to be a less suitable alternative compared to the use of a hydrophobic solution of silanes and siloxanes.

1. Introduction
People first became aware of the mutual symbiosis of man and the environment in the second half of the twentieth century, when industrial development and production began to have a significant impact on all components of the environment in a negative direction. At present, a number of ecological projects have been created, the aim of which is to eliminate the negative impact of man on the environment. The EU's approach to waste management is based primarily on waste prevention, followed by recycling, reprocessing and incineration of waste, and finally only as a last resort in landfills. The aim was to reduce the volume of waste to be disposed of by around 20% from 2000 levels by 2010 and by a further 50% by 2050 [1-3].

Construction and demolition wastes are wastes that arise as a result of the execution of construction work, as well as work performed during the maintenance of buildings, during the reconstruction of buildings or the removal (demolition) of buildings. It consists of a range of materials such as concrete, brick, wood, glass, metals, plastics or excavated soil. Many of them can be polluted or contaminated with hazardous substances, making this waste hazardous. With proper management of construction and demolition waste generation and a specified method of their management, construction waste can be an important source of secondary raw materials [4-6].

For example, such recovery of construction waste contributes to the conservation of natural raw material resources, while it efficient recycling reduces the need to extract gravel, sand and other minerals used in construction. [7,8].

Construction and demolition waste is part of the most important waste streams in the EU, amounting to around 750 million tons per year. Across the European Union, different definitions of construction and demolition waste are used, making comparisons between countries difficult. Construction and demolition waste has a high potential for recycling and reuse, as some of its components have a high value of input sources. Given the importance of this waste and the lack of comprehensive information on the situation of construction and demolition waste management in the Member States, it required an in-depth analysis of the situation, which includes identifying best waste treatment practices and identifying key factors for achieving sustainable construction and demolition waste management [9-11].
During construction or reconstruction, construction waste is generated, which is basically almost 100% reusable. Depending on the quality of the materials thus obtained, the method of removing old structures, the possibilities of processing, such material can be used in various new structural layers and for various purposes [12].

Brick waste is most often generated by demolition or maintenance of various masonry structures. It is usually composed of fired clay (clay), but it can also be a raw clay called “charged”, these are bricks made of raw, unfired clay. It is also possible to include tiles made of burnt clay and similar products. This waste belongs to the group of inert waste and is free of hazardous substances. The processing of brick waste produces the output material, namely recycled brick. The quality of the resulting recycled material is influenced not only by the technology itself, but also by the organization of work and the overall logistics system of the recycling facility [13-15].

In the first step, is removed foreign substances such as e.g. wood and iron. Crushing takes place on jaw or impact crushers, where the reinforcement is removed. In the last step, the recycled brick aggregate (RBA) is sorted according to grain size [16-18].

The paper is focused on the verification of the use of recycled brick aggregate as a full-replacement substitute for aggregates of the 4/8 mm fraction in concrete. An important part of the experiment is the treatment of recycled brick aggregate with selected impregnating substances with the intention of reducing the absorption coefficient of the selected material.

2. Material and Methods

The filler is one of the main components of concrete in the production process and 2 different types of fillers were used in our experiment. The first was the natural aggregate (NA) fraction 0/4 mm, while the fraction 4/8 mm was recycled brick aggregate (RBA), which came from the building for agricultural purposes.

Portland cement of strength class 42.5 R meeting the requirements of the standard STN EN 197-1 was used as a binder. Water from the laboratory, which meets the requirements of mixing water in concrete according to the standard STN EN 1008, was used to hydrate the cement. BERAMENT HT 25-1 plasticizer was used to improve the properties of the proposed concrete mix.

The whole process of treatment of recycled brick started with crushing bricks with a jaw crusher. The crushed bricks were subjected to sieve analysis, where the required 4/8 mm fraction was collected. This material was subsequently used in the production of experimental concrete, but it has one negative property - water absorption. With its significant absorbency, recycled brick aggregate contributes to the elimination of the strength characteristics of concrete. Therefore, it is necessary to reduce the absorbency of this recycled material. To prevent this, hydrophobizing/water-repellent additives to reduce the absorbency of the material was development. When the surface of the material is impregnated, the pores and capillaries are filled in the surface layer with the impregnating substance and thus the surface is closed. In our experiment, we used a specific water glass (1. treatment) and a hydrophobizing solution of an emulsion of silanes and siloxanes (2. treatment).

The treatment of the recycled brick aggregate itself consisted in being placed in a bath with an impregnator (water glass or hydrophobizing solution) for 48 hours. After a set time, the drying process was followed at room temperature of 20 °C for 48 hours. The recyclate was stirred regularly to dry as well as possible. Soaking in a bath and drying of the RBA is shown in Figure 1.
After treatment of the material, selected properties were monitored, which are described together with the values in Table 1.

Table 1. Real density and water absorption of starting and treated aggregates.

| Properties               | Natural aggregate 0/4 mm | RBA 4/8mm | RBA 4/8 mm (1. treatment) | RBA 4/8 mm (2. treatment) |
|--------------------------|--------------------------|-----------|--------------------------|----------------------------|
| Real density [kg/m³]     | 2650                     | 1560      | 2080                     | 1830                       |
| Water absorption [%]     | 5.3                      | 25        | 3                        | 9                          |

In order to monitor the behavior of RBA in the concrete mix, a reference mixture and two variants of it were designed using modified RBA (Table 2). All mixtures were designed with the same water coefficient $w/c = 0.49$. In the preparation of the reference sample "RR", natural aggregate fraction 0/4 mm and starting RBA fraction 4/8 mm was used. The sample marked "1-20" contained, in addition to natural aggregate 0/4 mm, a RBA fraction of 4/8 mm, which was treated with water glass of sodium silicate. The mixture "3-20" differed from the previous one only by the method of treatment of the 4/8 mm RBA, soaking in the hydrophobizing solution (emulsion of silanes and siloxanes).

Table 2. Composition of experimental mixtures per m³.

| Composition/Mixture       | RR  | 1-20 | 3-20 |
|---------------------------|-----|------|------|
| CEM I 42.5 R [kg]         | 370 | 370  | 370  |
| Water [kg]                | 180 | 180  | 180  |
| NA 0/4 mm [kg]            | 1100| 1100 | 1100 |
| RBA 4/8 mm [kg]           | 425 | 594  | 523  |
| BERAMENT HT 25-1[kg]      | 2.2 | 2.2  | 2.2  |
| w/c [-]                   | 0.49| 0.49 | 0.49 |

From the raw materials described above, fresh concrete mixtures were prepared, which were filled into molds with an edge of 100 mm. The molds were vibrated and left for 24h under laboratory conditions. After demolding, the samples were placed in the water. The real density and especially the compressive strength were monitored on the experimental samples in two time intervals, 28 and 60 days of hardening.
3. Results and Discussion
The determination of the real density was performed on test specimens measuring 100 x 100 x 100 mm. The test specimens were weighed and their dimensions were measured. From the data obtained, the real density was calculated as the ratio of weight to body volume. The values were determined on three samples, and the resulting real density was determined as their average. A comparison of the real densities of the individual samples is shown in Figure 2. According to the achieved real densities of all test specimens, we can state that the reference sample (sample RR) together with the first treatment of recycled aggregate (sample 1-20), which water glass was used as an impregnator, after 28 and 60 days this samples can be classify it into the class of normal concrete, whose real density is in the range from 2000 - 2800 kg/m$^3$. In the tested sample with the second modification of the recycled aggregate (sample 3-20), a significantly lower real density was obtained. After 28 and 60 days of hardening, this sample was at a level of less than 2000 kg/m$^3$, which is class of lightweight concrete. This low value of real density can also be attributed to the action of the silane-siloxane solution emulsion hydrophobizing solution on the recyclate.

![Figure 2. Real density of samples after 28 and 60 days.](image)

On test specimens measuring 100 x 100 x 100 mm, compressive strength tests were performed by the destructive method after 28 and 60 days of hardening according to the standard STN EN 12390-3. View of the test machine and the sample after the compressive strength test shows Figure 3.

![Figure 3. View of the test machine and the sample after the compressive strength test.](image)
From the resulting strengths (Figure 4), we can state that the treated recycled brick aggregate achieved much lower compressive strength than the untreated recycled brick aggregate.

![Figure 4. Compressive strength of samples after 28 and 60 days.](image)

The final strength was affected by the ratio of recycled and the amount of cement. Sample 1-20 showed the lowest strengths, where the largest amount of recycled brick aggregate was used. The reduced strength of concretes could be caused by the inappropriate development of interaction with the cement matrix in the concrete, resp. due to the relatively high absorbency of the treated recycled brick, which was not taken into account in the production of concrete samples. For compressive strengths after 60 days, an increase in strength was observed, for sample 1-20 by 12% and for sample 3-20 to 21%.

4. Conclusion
The options we have chosen to eliminate the water absorption of RBA have proved to be ineffective. From the experiment it can be concluded that increasing the amount of RBA based on the real bulk density and the same amount of cement (1 m3) is at the expense of the resulting strength of concrete. In any case, the water absorption of the recyclates must be taken into account and the required amount of mixing water must be added to the mixture. Untreated RBA appears to be the best option for partial replacement of aggregates compared to treated material. Of the treated RBA, the recyclate achieved better final properties, where a hydrophobic solution of silanes and siloxanes was used as an impregnator. RBA treated with water glass seems to be the least suitable treatment alternative, which showed very poor properties of hardened concrete samples in all tests.

Acknowledgments
This research has been carried out within the Slovak Scientific Grant Agency VEGA [Grant Number: 1/0524/18].

References
[1] Colangelo F, Navarro T.G, Farina, I and Petrillo A 2020 International Journal of Life Cycle Assessment 9 1790-1804
[2] Junak J and Stevułova N 2011 11th Int. Mul. Sci. Geo. SGEM 2011 (Albena) vol 3 (Sofia: STEF92 Technology Ltd.) pp 567–572
[3] Migliore M, Talamo C and Paganin G 2020 Springer Tracts in Civil Engineering 1-44
[4] Junak J and Sicakova A 2017 Buildings 8 Article number 2
[5] Castillo Castillo A and Angelis-Dimakis A 2019 *Journal of Environmental Management* **247** 439-448
[6] Ge P, Huang W, Zhang J, Quan W and Guo Y 2021 *Construction and Building Materials* **304** Article number 124584
[7] Junakova N and Junak J 2017 *Procedia Engineering* **180** 1292-11297
[8] Junakova N and Balintova M 2012 *Chemical Engineering Transaction* **28** 265-270
[9] Nußholz J.L.K, Nygaard Rasmussen F and Milios L 2019 *Resources, Conservation and Recycling* **141** 308-316
[10] Szafranko E 2019 *Engineering for Rural Development* **18** 1510-1515
[11] Singovszka E, Junakova N and Balintova M 2016 *Solid State Phenomena* **244** 240-245
[12] Ondova M and Sicakova A 2016 *Materials* **3** Article number 156
[13] Sicakova A, Spak M, Kozlovska M and Kovac M 2017 *Advances in Materials Science and Engineering* Article number 713981
[14] Junak J, Stevulova N and Ondova M 2014 *Pollack Periodica* **9** 95-104
[15] Boudina T, Benamara D and Zaitri R 2021 *Frattura ed Integrita Strutturale* **57** 50-62
[16] Dang J, Zhao J, Pang S.D and Zhao S 2020 *Construction and Building Materials* **262** Article number 120032
[17] Svoboda J, Vaclavik V, Dvorsky T and Zajac R 2018 *IOP Conference Series: Materials Science and Engineering* Issue 1 Article number 138437
[18] Klus L, Vaclavik V, Dvorsky T, Svoboda J and Papesch R 2017 *Buildings* **4** Article number 120