Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIV, 2025
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

THE INTEGRATION OF CERAMIC WASTE AS A PARTIAL SUBSTITUTE OF NATURAL AGGREGATES IN EXPERIMENTAL CONCRETE RECIPES

Mircea SĂLCUDEAN[1], Maria POPA[2]

[1]Lucian Blaga University of Sibiu, Faculty of Engineering, Doctoral School,
10 Victoriei Blvd, 550024, Sibiu, Romania
[2]"1 Decembrie 1918" University of Alba Iulia, Faculty of Economic Sciences,
15-17 Unirii Street, 510009, Alba Iulia, Romania

Corresponding author email: salcudean.mircea@uab.ro

Abstract

The work aimed to show that it is feasible to integrate ceramic waste from the construction industry and demolitions into the content of concrete recipes, as a partial replacement for natural aggregates in standard concrete recipes. The integration of these wastes into the composition of concrete is of particular importance because, on the one hand, we reduce the amount of waste resulting from the construction industry, and on the other hand, we achieve savings of raw materials used in the manufacture of concrete, coming from exhaustible natural resources. Compared to the standard C16/20 concrete recipe used as the control sample in the experimental recipe, the natural aggregates of size 4-8 mm were partially replaced by 50% ceramic waste. Various physical-mechanical tests were performed, such as determining the density of fresh concrete, determining the compressive strength of concrete containing ceramic waste compared to a standard concrete recipe containing natural aggregate. Following tests on experimental recipes, very good results were obtained in determining the compressive strength, which were similar to the test results on standard concrete recipes.

***Key words**: ceramic waste, natural aggregates, concrete.*

INTRODUCTION

Concrete, which due to its qualities, strength, durability, versatility and the fact that it can be cast into almost any shape and reproducing any surface texture, is the most used construction material in the world (Shelton et al., 1982). Concrete is a mixture of materials composed of 60-75% sand and gravel, 15-20% water and 10-15% binders, which is the basic ingredient that binds the composition. The Romans used a volcanic ash as a binder in the composition of concrete but currently, the binder used is called Portland cement (Gagg, 2014). Given that aggregates occupy from 60 to 75% of the volume of concrete, this influences its physical-mechanical properties. The strength of normal concrete is affected by the size of the aggregates, therefore optimal dosage is very important to obtain the best results (Albarwary et al., 2017). Very rapid urbanization, coupled with population growth, has led to an increasing consumption of building materials (Kamali et al., 2019). The increase in global consumption of construction materials has inevitably led to high pollutant emissions and an increasing generation of waste. The production of cement, steel and concrete has the heaviest environmental burden during their manufacture (Huang et al., 2020). The construction industry is the largest consumer of material resources (40-60% of the total raw material extractions), water, and energy (40% of energy consumption) (Spence & Mulligan, 1995). Intensive activities in the construction industry are considered to be the main responsible for the scarcity of natural resources (Ghisellini et al., 2018), including water, crushed aggregates , increased pollution and demands for materials (Eray et al., 2019).
Construction waste is primarily caused by demolition activities ,equivalent to 40% of total waste (de Castro & de Brito, 2013) almost half of the total waste generated worldwide (Nasir et al., 2017), causing both noise and pollution (Çimen, 2021). The construction industry is the main generator of waste, accounting for up to 40% of urban solid waste (Chen et al., 2019). Due to the high consumption of natural aggregates, the use of recycled aggregates from construction and demolition waste in concrete is becoming increasingly widespread these days, with concrete made with recycled aggregates

potentially becoming the most widely used material in the coming years (Chitra, 2018).

The use of construction and demolition waste in concrete manufacturing, especially as raw materials replacing natural aggregates, is one of the most efficient ways to utilize these wastes (M. Ramesh & Kumaravel, 2014). Ceramic aggregate is resistant to abrasion. Ceramic products also have high strength, wear resistance over time, etc (Ray et al., 2021). Therefore, the use of these industrial wastes in concrete as a replacement for aggregates can be an effective solution in the recycling process of waste from construction and demolition (Ay & Ünal, 2000).

Aggregates from ceramic waste have similar properties to those from natural rocks (Halicka et al., 2013).

Unlike glass and rubber waste, ceramic waste has a porous structure that allows binder penetration, improving compressive strength in concrete (Sabbrojjaman et al., 2024).

Few studies have explored using ceramic waste as an aggregate substitute in concrete. Given that ceramic waste accounts for about 30% of daily tile production, or roughly 22 billion tons annually worldwide (Ahmad et al., 2023; Alyousef et al., 2021), its incorporation into concrete could help conserve natural resources and benefit the environment (Meena et al., 2022).

The rising cement production over the years, as shown in Figure 1, and the corresponding increase in concrete production, underscore the need to incorporate greater amounts of recycled aggregates in concrete (Production Volume of Cement Worldwide from 1995 to 2023, n.d.).

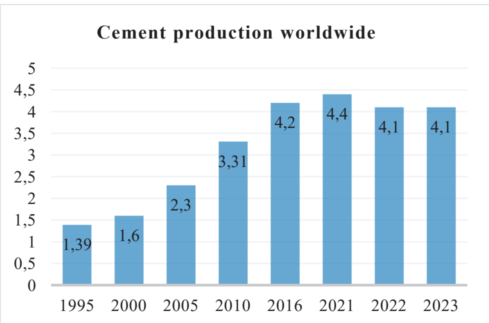

Figure 1.Cement production worldwide from 1995 to 2023 (Billion metric tons)

MATERIALS AND METHODS

According to a study published by Eurostat in 2018, an estimated amount of construction and demolition waste is generated in the European Union at over 850 million tons (Chapter 36:Production and Management - The Problem, n.d.) .This figure represents approximately 25-30% of all waste generated in the EU in 2020, reaching approximately 37.5% of total waste (Villoria Sáez & Osmani, 2019). Waste management is essential because the construction industry generates huge amounts of waste (Can & Taş, 2022). As the construction industry has a major influence on other industries, waste reuse can make a significant contribution to the circular economy (Aboginije et al., 2021). A medium and long-term estimate shows that almost 80% of the construction and demolition waste generated is recyclable and usable (Begum et al., 2010; Huang et al., 2020).

To practically demonstrate the usefulness of various wastes from the construction industry and from demolitions, it is necessary to manufacture some experimental recipes containing waste and then to compare various parameters of these recipes with the parameters of standard concrete recipes.

To do this, scraps of ceramic products (plates and tiles) from construction and demolition waste, 4-8 mm in size, shown in Figure 2, were used.

The samples will be tested for compression resistance and their density will be calculated.

The device for testing compressive strength is the Matest C058-05N automatic concrete press with a maximum capacity of 2000KN, which is shown in Figure 3.

Figure 2. Aggregates from ceramic waste size 4-8 mm

Figure 3. Matest 2000KN concrete press

RESULTS AND DISCUSSIONS

To verify and test the experimental recipes with ceramic waste content from construction and demolition, as a control, a sample prepared according to the standard recipe of concrete C16/20 is used.
C16/20 concrete, also called B250 in the past, is the most popular class of concrete used in constructions in Romania. Mainly used in the structures of houses and in the foundations of low-rise buildings, concrete class C16/20 (B250), is a common concrete preferred in general for civil constructions and various related construction elements.
C16/20 (B250) concrete is used for the construction of foundations, beams, columns, belts, sidewalks and other elements (C16/20(B250) concrete n.d.). The components of the standard recipe for concrete C16/20 in Table 1 are according to the recipe from the concrete station belonging to S.C. ELIS PAVAJE S.A Petrești, the quantities being presented in cubic meters (m^3) but also in percentage of 0.5% of this quantity, being used in the preparation of experimental recipes.

Table 1. Concrete recipe C16/20

Component	kg/m^3	0.5% (kg)
Cement 42.5 R	295	1.475
Aggregate 0-4 mm 43%	789	3.945
Aggregate 4-8 mm 20%	367	1.835
Aggregate 8-16 mm 37%	679	3.395
Water	170	0.85

Figure 4 shows photos of the grades and the cement used in the preparation of the standard C16/20 concrete recipe as well as in the composition of the experimental recipes with the addition of ceramic waste and polystyrene.
Aggregates in concrete recipes can be:

- Natural aggregates from ballast pits - material excavated from pits or riverbeds consists of a mixture of sand and gravel;
- Natural aggregates from quarries - the rock (raw material) is crushed with a crusher and sorted by size using a sorting station.

The aggregates used in these recipes are ballast aggregates.

Figure 4. Components of concrete recipes

In order to prepare these experimental recipes, waste ceramic products from construction and demolition were used (sandstones and earthenware), as a partial substitute for some aggregates. Figure 5 shows the process of crushing ceramic waste manually using a Hammer.

Figure 5. The grinding process of ceramic waste

To sort the crushed ceramic remains, an electric sieving device was used to determine the granularity, as shown in Figure 6. Following this size separation process, the required quantity was obtained to replace the standard 4-8 mm aggregate fraction in the experimental recipe.

Figure 6. Size sorting of shredded ceramic waste

The Figure 7 shows how to prepare the experimental recipes manually by incorporating the waste prepared in the previous stage. These wastes used replaced the 4-8 mm grade with 50% ceramic waste in the experimental recipe.

Figure 7. Preparation of experimental recipes

Figure 8 shows the manual homogenization of the experimental recipe components with the help of a trowel and Table 2 presents the experimental recipe components.

Table 2. Experimental concrete recipe

Component	Quantity (kg)
Cement	1.475
0-4 mm river aggregate	3.945
4-8 mm river aggregate	0.9175
4-8 mm ceramic aggregate	0.9175
8-16 mm river aggregate	3.395
Water	0.85

Figure 8. Homogenization of experimental recipe components

Figure 9 shows the concrete samples resulting from the preparation of the experimental recipes, poured into standard models (3 samples to be tested at 7 days and 3 samples to be tested at 28 days), then it is kept for 24 hours in these patterns, after which it is removed and placed in the sample storage basin for 28 days at a constant temperature of 20 degrees Celsius, according to NE 012/2-2010.
Or performed compressive strength measurement tests 7 days and 28 days after their manufacture according to SR EN 12390-3:2002 Test on hardened concrete. Part 3: Compressive strength of specimens.
The tests were done for the standard recipe as well as for the experimental recipes. Our determinations of the fresh and hardened concrete densities of these samples were also made. Figure 10 shows the tests to determine the compressive strength carried out.

Figure 9. Concrete samples immersed in the storage basin

Following the tests performed regarding the compressive strength at 7 days and at 28 days, as well as the density, the results presented in Table 3 were obtained.

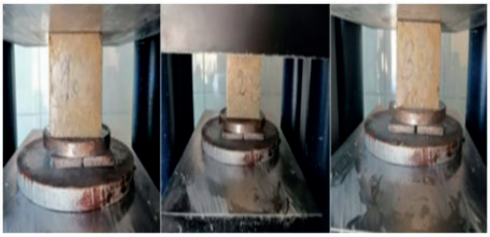

Figure 10. Performing compressive strength tests

Table 3. The results of the tests performed

Concrete type	Sample density (kg/m^3)	Compressive strength 7 days (MPA)	Compressive strength 28 days (MPa)
C16/20	2310	11.850	17.410
C16/20+ ceramic	2274	13.486	19.456

Compared to other research on the use of ceramic waste as a partial substitute for natural aggregates in concrete composition in terms of compressive strength, the basic trend is not significantly different from conventional concrete retention with natural aggregates.
Table 4 presents previous results of researchers who have addressed the topic of partial replacement of natural aggregates with ceramic waste, using different concrete recipes.

Table 4. Results of tests conducted by other researchers

Contains ceramic waste	Results	Authors
For 0% replacement	32.29 MPa	(Bommisetty et al., 2019)
For 25% replacement	33.48 MPa	(Bommisetty et al., 2019)
For 0% replacement	39 MPa	(Siddique et al., 2018)
For 40% replacement	45.16 MPa	(Siddique et al., 2018)
For 0% replacement	52.9 MPa	(Nepomuceno et al., 2018)
For 50% replacement	48.1 MPa	(Nepomuceno et al., 2018)
For 0% replacement	23 MPa	(Awoyera et al., 2018)
For 50% replacement	25 MPa	(Awoyera et al., 2018)
For 0% replacement	46.2 MPa	(Anderson et al., 2016)
For 50% replacement	45.2 MPa	(Anderson et al., 2016)

CONCLUSIONS

Preliminary tests using recipes incorporating construction industry waste were conducted, providing reference quantities for developing subsequent experimental formulations.
The use of construction and demolition of waste offers several benefits:

- Reduction of waste generated by industry;
- Conservation of non-renewable natural resources;
- Decreased demand for storage space.

Recommend and support the idea of using waste in the construction industry in the concrete manufacturing process and the search for the new experimental recipe with the highest possible content of waste.
The results of the tests performed on these experimental concrete recipes confirm that the partial replacement of waste with waste (the natural aggregates of size 4-8 mm were partially replaced by 50% with ceramic waste) is viable and can successfully replace these components in the composition of the concrete. In future experiments, it is intended to integrate as much waste from construction and demolition into the composition of concrete to use them and to get results as close to standard recipes.
The compressive strength of experimental concrete containing ceramic waste increased by up to 12% compared to standard concrete.
The results obtained show that research can be continued by progressively integrating increasing amounts of ceramic waste as a substitute for natural aggregates in the concrete structure. Once this research is continued and practically demonstrated, new paragraphs can be drawn up in construction standards so that ceramic waste can become a more common choice among recycled aggregates.
Future studies should evaluate the long-term behavior of ceramic waste concrete, including freeze-thaw resistance, shrinkage, water absorption, and sulfate attack resistance to ensure its practical application in various environmental conditions.

ACKNOWLEDGEMENTS

This research activity was carried out with the support of SC ELIS PAVAJE SRL, a company

whose object of activity is the manufacture of paving stones and various communication paths, which uses various waste from CDW in their manufacturing process, and which shows a great interest in using as much waste as possible in their products.

REFERENCES

Aboginije, A., Aigbavboa, C., & Thwala, W. (2021). A Holistic Assessment of Construction and Demolition Waste Management in the Nigerian Construction Projects. *Sustainability*, *13*(11), 6241. https://doi.org/10.3390/su13116241

Ahmad, J., Alattyih, W., Jebur, Y. M., Alqurashi, M., & Garcia-Troncoso, N. (2023). A review on ceramic waste-based concrete: A step toward sustainable concrete. *Reviews on advanced materials science*, *62*(1). https://doi.org/10.1515/rams-2023-0346

Albarwary, I. H. M., Aldoski, Z. N. S., & Askar, L. K. (2017). Effect of Aggregate Maximum Size upon Compressive Strength of Concrete. *The Journal of The University of Duhok*, *20*(1), 790–797. https://doi.org/10.26682/sjuod.2017.20.1.67

Alyousef, R., Ahmad, W., Ahmad, A., Aslam, F., Joyklad, P., & Alabduljabbar, H. (2021). Potential use of recycled plastic and rubber aggregate in cementitious materials for sustainable construction: A review. *Journal of Cleaner Production*, *329*, 129736. https://doi.org/10.1016/j.jclepro.2021.129736

Anderson, D. J., Smith, S. T., & Au, F. T. K. (2016). Mechanical properties of concrete utilising waste ceramic as coarse aggregate. *Construction and Building Materials*, *117*, 20–28. https://doi.org/10.1016/j.conbuildmat.2016.04.153

Awoyera, P. O., Ndambuki, J. M., Akinmusuru, J. O., & Omole, D. O. (2018). Characterization of ceramic waste aggregate concrete. *HBRC Journal*, *14*(3), 282–287. https://doi.org/10.1016/j.hbrcj.2016.11.003

Ay, N., & Ünal, M. (2000). The use of waste ceramic tile in cement production. *Cement and Concrete Research*, *30*(3), 497–499. https://doi.org/10.1016/S0008-8846(00)00202-7

Begum, R. A., Satari, S. K., & Pereira, J. J. (2010). Waste Generation and Recycling: Comparison of Conventional and Industrialized Building Systems. *American Journal of Environmental Sciences*, *6*(4), 383–388. https://doi.org/10.3844/ajessp.2010.383.388

Bommisetty, J., Keertan, T. S., Ravitheja, A., & Mahendra, K. (2019). Effect of waste ceramic tiles as a partial replacement of aggregates in concrete. *Materials Today: Proceedings*, *19*, 875–877. https://doi.org/10.1016/j.matpr.2019.08.230

Can, G., & Taş, E. F. (2022). Classification of Construction Waste. *In Proceedings of 6th International Project and Construction Management Conference*, 143–150.

Chapter 36:production and management - The problem. (n.d.). https://www.eea.europa.eu/publications/92-826-5409-5/page036new.html#:~:text=It is estimated that Europe,at around 3 per cent.

Chen, W., Jin, R., Xu, Y., Wanatowski, D., Li, B., Yan, L., Pan, Z., & Yang, Y. (2019). Adopting recycled aggregates as sustainable construction materials: A review of the scientific literature. *Construction and Building Materials, 2018,* 483-496, https://doi.org/10.1016/j.conbuildmat.2019.05.130

Chitra, K. R. (2018). Concrete Using Recycled Aggregates. *International Journal of Civil Engineering and Technology*, *8*(9), 413–419. http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=9

Çimen, Ö. (2021). Construction and built environment in circular economy: A comprehensive literature review. *Journal of Cleaner Production*, *305*, 127180. https://doi.org/10.1016/j.jclepro.2021.127180

de Castro, S., & de Brito, J. (2013). Evaluation of the durability of concrete made with crushed glass aggregates. *Journal of Cleaner Production*, *41*, 7–14. https://doi.org/10.1016/j.jclepro.2012.09.021

Eray, E., Sanchez, B., & Haas, C. (2019). Usage of Interface Management System in Adaptive Reuse of Buildings. *Buildings*, *9*(5), 105. https://doi.org/10.3390/buildings9050105

Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis*, *40*, 114–140. https://doi.org/10.1016/j.engfailanal.2014.02.004

Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, *178*, 618–643. https://doi.org/10.1016/j.jclepro.2017.11.207

Halicka, A., Ogrodnik, P., & Zegardlo, B. (2013). Using ceramic sanitary ware waste as concrete aggregate. *Construction and Building Materials*, *48*, 295–305. https://doi.org/10.1016/j.conbuildmat.2013.06.063

Huang, B., Gao, X., Xu, X., Song, J., Geng, Y., Sarkis, J., Fishman, T., Kua, H., & Nakatani, J. (2020). A Life Cycle Thinking Framework to Mitigate the Environmental Impact of Building Materials. *One Earth*, *3*(5), 564–573. https://doi.org/10.1016/j.oneear.2020.10.010

Kamali, M., Hewage, K., & Sadiq, R. (2019). Conventional versus modular construction methods: A comparative cradle-to-gate LCA for residential buildings. *Energy and Buildings*, *204*, 109479. https://doi.org/10.1016/j.enbuild.2019.109479

M. Ramesh, K. S. K., & Kumaravel, T. K. and A. (2014). Construction Materials From Industrial Wastes-A Review of Current Practices. *International Journal of Environmental Research and Development*, *4*(4), 317–324. https://d1wqtxts1xzle7.cloudfront.net/40835473/ijerdv4n4spl_08-libre.pdf?1450720294=&response-content-disposition=inline%3B+filename%3DIjerdv4n4spl_08.pdf&Expires=1739277693&Signature=euHL1jzyV

zPd~fVRm~Mn07LoscmDU0jNUavkenLkU1qcWi9m3H3m6oVGgfQvOWSIwho-RY5

Meena, R. V., Jain, J. K., Chouhan, H. S., & Beniwal, A. S. (2022). Use of waste ceramics to produce sustainable concrete: A review. *Cleaner Materials*, *4*, 100085. https://doi.org/10.1016/j.clema.2022.100085

Nasir, M. H. A., Genovese, A., Acquaye, A. A., Koh, S. C. L., & Yamoah, F. (2017). Comparing linear and circular supply chains: A case study from the construction industry. *International Journal of Production Economics*, *183*, 443–457. https://doi.org/10.1016/j.ijpe.2016.06.008

Nepomuceno, M. C. S., Isidoro, R. A. S., & Catarino, J. P. G. (2018). Mechanical performance evaluation of concrete made with recycled ceramic coarse aggregates from industrial brick waste. *Construction and Building Materials*, *165*, 284–294. https://doi.org/10.1016/j.conbuildmat.2018.01.052

Production volume of cement worldwide from 1995 to 2023. (n.d.). https://www.statista.com/statistics/1087115/global-cement-production-volume/

Ray, S., Haque, M., Sakib, M. N., Mita, A. F., Rahman, M. D. M., & Tanmoy, B. B. (2021). Use of ceramic wastes as aggregates in concrete production: A review. *Journal of Building Engineering*, *43*, 102567. https://doi.org/10.1016/j.jobe.2021.102567

Sabbrojjaman, M., Liu, Y., & Tafsirojjaman, T. (2024). A comparative review on the utilisation of recycled waste glass, ceramic and rubber as fine aggregate on high performance concrete: Mechanical and durability properties. *Developments in the Built Environment*, *17*, 100371. https://doi.org/10.1016/j.dibe.2024.100371

Shelton, David P. and Harper, J. M. (1982). G82-623 An Overview of Concrete as a Building Material. *Historical Materials* *□mUniversity of Nebraska-Lincoln Extension*, *603*. https://www.researchgate.net/publication/266468220_G82-623_An_Overview_of_Concrete_as_a_Building_Material

Siddique, S., Shrivastava, S., Chaudhary, S., & Gupta, T. (2018). Strength and impact resistance properties of concrete containing fine bone china ceramic aggregate. *Construction and Building Materials*, *169*, 289–298. https://doi.org/10.1016/j.conbuildmat.2018.02.21

Spence, R., & Mulligan, H. (1995). Sustainable development and the construction industry. *Habitat International*, *19*(3), 279–292. https://doi.org/10.1016/0197-3975(94)00071-9

Villoria Sáez, P., & Osmani, M. (2019). A diagnosis of construction and demolition waste generation and recovery practice in the European Union. *Journal of Cleaner Production*, *241*, 118400. https://doi.org/10.1016/j.jclepro.2019.118400