



KONFERENCIAKÖTET

Conference Proceedings

**Nemzetközi tudományos konferencia
a Magyar Tudomány Ünnepe alkalmából**
International Scientific Conference
on the Occasion of the Hungarian Science Festival

Sopron, 2022. november 3.
3 November 2022, Sopron

**TÁRSADALOM – GAZDASÁG – TERMÉSZET:
SZINERGIÁK A FENNTARTHATÓ FEJLŐDÉSBEN**

SOCIETY – ECONOMY – NATURE: SYNERGIES IN SUSTAINABLE DEVELOPMENT

Szerkesztők / Editors:

OBÁDOVICS Csilla, RESPERGER Richárd, SZÉLES Zsuzsanna, TÓTH Balázs István

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LEKTORÁLT TANULMÁNYOK / PEER-REVIEWED STUDIES

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SOPRONI EGYETEM KIADÓ

UNIVERSITY OF SOPRON PRESS

SOPRON, 2023

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Felelős kiadó / Executive Publisher: Prof. Dr. FÁBIÁN Attila,
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ISBN 978-963-334-450-7 (pdf)

DOI: [10.35511/978-963-334-450-7](https://doi.org/10.35511/978-963-334-450-7)

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Cost Analysis of Sustainable Concrete Production Using Waste Nanoparticles

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Abstract

In building constructions, considering sustainability, there is an increased interest in a reduction in landfills, converting waste materials into nanomaterials by using for example waste materials like waste grain wheat, waste ceramic, and slag, decreasing thus also the price of production of concrete and enhancing the properties of construction products. This article will focus on using waste ceramic powder and blast furnace slag as replacements for cementitious materials. “Conventional concrete” (Cc) is produced by mixing 100% cement + sand + water whilst “Sustainable concrete” (Sc) is produced from a mix of sand + water + 47.5 % cement+ 50% of waste-based Supplementary Cementitious Materials (SCMs) consisting of 25 % of Waste Ceramic Powder (WCP) and 25% of Blast Furnace Slag (BFS)) +2.5% of nano SiO₂. This article makes an economic comparison between these two types of concrete, showing that whilst the cost of 1 m³ Cc is approximately 100 \$, the cost of 1 m³ Sc is 60 \$, having the same mechanical properties. By using Sc for construction works leads to saving huge quantities of raw material used for cement production. The economic evaluation showed savings in cost around 40% by partial substitution of cement with waste-based/reused cementitious materials, being a promising result for a sustainable construction industry.

Keywords: eco-concrete, waste materials, sustainable, nanoparticles

JEL Codes: Q53, L60, L61

1. Introduction

Several studies focus on sustainable concrete mortar production. However, there are limited number of studies that focus on the comparative cost analysis of sustainable concrete mortar production with nanomaterials. It is widely considered, that engineering construction works involving concrete are not environmentally friendly, because of cement. As basic component of concrete, cement is responsible for a major CO₂ emission during its production and furthermore results high amount of dust and consumes relevant raw material reserves (limestone, clay). The concrete mortar contains cement, sand, and water. Although cement volume takes only 10% to

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40% of the total volume of the concrete mortar mixture, when the cement interacts with the water, will have a relatively strong bond strength that bonds the sand particles together (Ghrici et al., 2006).

This study promotes greener buildings by suggesting a more sustainable construction practice by substituting environmentally weak cement with waste-based materials and reducing the cost of concrete, thus the principle of more sustainable construction is achieved. The use of waste materials is a creative start in terms of green design. This principle promotes using either waste materials resulting as byproducts of construction products production processes or from the demolition of buildings at the engineering site, such as brick blocks or concrete structures,- as they can be reused as recyclable building materials (both end-life buildings and parts of buildings for renovation) (Jayaraman et al., 2015). Regrettably, one ton of cement production produces roughly an equal quantity of greenhouse gases (GHGs), like CO₂, and requires the use of 1.5-1.75 tons of raw materials like limestones for example. Nowadays, the average annual cement production has reached up to 2.8 billion tons, and expectations indicate an increase in the amount of cement production to 4 billion tons per year till 2050 (Abbas et al., 2022).

Nanoparticles are used in different applications and have received specific attention in the manufacturing of materials with new functionalities. These particles are used in concrete mortar also. In general these particles act on two levels: the first is chemical and the second is mechanical, where they enter the interfacial zone between the sand and cement to obtain a new good characteristic compared with conventional materials (Hanus & Harris, 2013; Biricik & Sarier, 2014). The concrete becomes denser and more durable than conventional mortar with improved mechanical properties, increases the mortar porosity, bleeding and segregation decrease and the cohesiveness of the mixtures improves (Guerrini & Corazza, 2008; Setiati, 2017).

On the other hand, there is a relevant pollution and waste generation associated both with the production processes of these materials and solid pollutants from building with concrete, ceramics, and steel. The total waste in construction in the United States, in 90% comes from the demolition of structures, while waste generated during construction accounts for less than 10% (US EPA-OLEM, 2016). In the European Union (EU), there is now significant emphasis on recycling building materials and adopting a cradle-to-grave ideology when it comes to building design, construction, and demolition. In the 2016 EU construction and demolition waste management Protocol, they emphasize the benefits beyond financial gains for recycling such as job creation and reduced landfilling. They also emphasize the consideration of supply and demand geography; if the recycling plants are closer to urban areas than the aggregate quarries this can incentivize companies to use this recycled product even if it is not initially cheaper. In Austria, there are new improvements in the recycling of unusable wood products to be burnt for the creation of cement, which offsets the carbon footprint of both products. In the other hand approximately 15 to 30 percent of production in the ceramic industry goes as solid waste material (European Commission, 2018) and Annual Blast Furnace Slag produced in 2014 was about 170–250 million tons worldwide, based on typical ratios of slag to steel output (Kanaan & El-Dieb, 2016).

This article aims to study the reduction of cement ratio in the concrete mix, in order to reduce the pollutants resulting from the cement production, reduction of the landfill by using waste materials as cement substitutes (like waste ceramic, slag and waste grain) and reduction of the cost of concrete to the half by using these waste materials.

2. Price analysis of concrete

In this part, prices in Iraq (the city of Mosul) were adopted as a model, taken from the website of the Iraqi Ministry of Planning (2022). The US dollar was considered as the official currency (referring to the dollar exchange rate during the month of October 2022) and thus it is adaptable to all countries.

Table 1: Materials and cost analysis

Material	Price	Note
Cement 1 ton	120\$	
Sand / m ³	20 \$	
Water / 1 m ³	1 \$	
Ceramic powder	20\$ front loader / 12 m ³ 80\$ dump truck / 12 m ³ 50\$ crushing machine and milling / 12m ³ 100\$ sieving the powder by Sieve No. 200	All this prices valid in 2022 October in Iraq / Mosul city Front loader=40\$ /hr. (collect WCP) Dump truck = 80 \$ (transport) crushing stone machine and milling= 250\$/hr. with production rate 100m ³ /hr. Sieving and separate the large particles by workers every worker taken 10\$ per day
BFS	10\$ front loader / 12 m ³ 80\$ dump truck / 12 m ³ 80\$ sieving the powder by Sieve size 200	
NGB	The production of 50 g of NGB costs = 15\$ (Zinad et al., 2020)	

Source: These results are provided by the manufacturer.

3. Experimental work

3.1. Material and method

1. Cement (OPC): The cement used was Ordinary Portland Cement (OPC), manufactured by the Badoosh factory. The Physical and chemical composition as provided by the manufacturer is given in Tables 2 and 3.

Table 2: Chemical composition of the OPC

Property	Test result (Percentage %)	Standard IQS, NO.5/1984
Oxide composition:		
Alumina, Al ₂ O ₃	5.6	3-8
Silica, SiO ₂	21.25	17-25
Ferric Oxide, Fe ₂ O ₃	2.74	0.5-6
Lime, CaO	62.55	60-67
Sulphuric Anhydride, SO ₃	2.54	Max. 2.8%
Magnesia, MgO	3.23	Max. 5%
Compound composition:		
C ₃ A	12.07	11.96-12.3
C ₂ S	34.20	28.61-37.9
C ₃ S	36.44	31.03-41.05

Source: These results are provided by the manufacturer.

Table 3: Physical properties of the OPC

Property	Test result	Standard IQS, No.5 1984
Fineness (Sieve size 170)	2%	Max. 10%
Specific surface “Blaine” (cm ² /g.)	3358.5	Min. 2250
Initial setting time	140 (min.)	45 (min.)
Final setting time	385 (min.)	600 (max.)
Specific gravity	3.14	-
Compressive strength (MPa)		
At 3 days	19.22	16.0 (min.)
At 7 days	27.88	(min.)

Source: These results are provided by the manufacturer.

2. Aggregate: Naturally available fine and coarse aggregates were used, and their properties were shown in Table 4. the sieve analysis was done by using the stander sieve size and calculating the sand weight percentage that passed through the stander sieve size, explained at ASTM C136.

Table 4: Grading and properties of fine aggregate

Sieve size (mm)	Percentage passing	Limits of specifications ASTM C136
9.5	100	100
4.75	98	95-100
2.36	92	80-100
1.18	84	50-85
0.60	57	25-60
0.30	23	5-30
0.15	3	0-10
Property	Result	
Bulk specific gravity	2.62	
Absorption (%)	0.70	

Source: This test was conducted at Northern Technical University Iraq laboratories by the author.

3. Super-plasticizer Admixture: High range water reducing admixtures (HRWRA) were used which conform to ASTM C494 Type A and F. Set retarding / High range water reducing / super-plasticizer admixture ASTM C494 type G: set retarding / high range water and super-plasticizer admixture standards.

Table 5: Superplasticizer properties

Structure the material	Naphthalene sulphonates based
Color	Brown
Density	1.148 – 1.208 kg/liter
Chloride content	< 0.1
Alkaline content	<5
*Obtained in +20 °C , 50% relative humidity condition	

Source: These results provided by the manufacturer (data sheet)

4. Waste ceramic: a siliceous and aluminous material, which possesses little or no cementitious value, but which will in the finely divided form, in the presence of moisture, react chemically with calcium hydroxide at normal temperature, to form compounds possessing cementitious properties (ASTM C125). The waste ceramic tiles are collected as broken pieces and grinded by a milling machine and Los Angeles machine as shown by Figure 1 to become powder with particle size passing the stainless steel woven-wire cloth sieve with 200 (75 μ m) opening size (Dawood et al., 2020).



Figure 1: Steps of WCP manufacturing
Source: Dawood et al. (2020)

5. Blast Furnace Slag: it is a nonmetallic hydraulic cement, consisting of silicates and aluminosilicates of calcium and other bases, developed in a molten condition, having a fineness about 400 - 600 m²/kg (by Blaine method test), the specific gravity is 2.85 - 2.95 with bulk density 1050 to 1375 kg/m³.

6. Water: Tap water

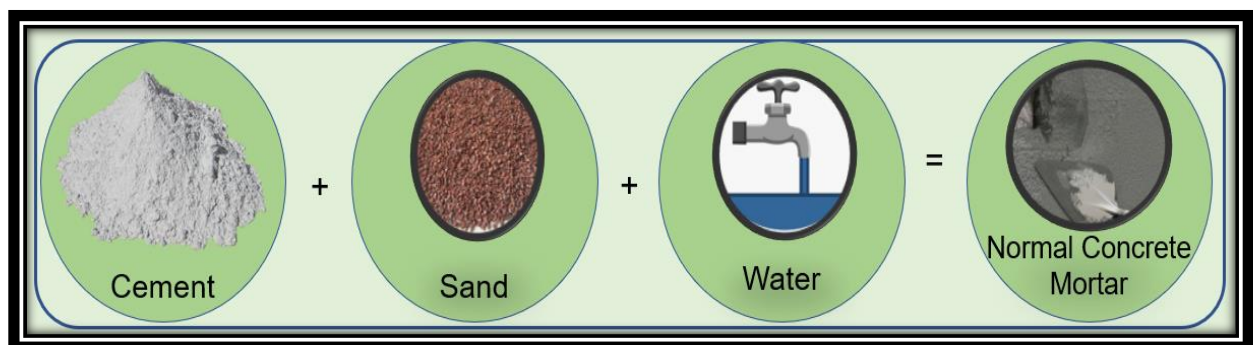


Figure 2: Conventional concrete mortar mixture
Source: Infographic by Zinad O.



Figure 3: Sustainable concrete mortar mixture
Source: Infographic by Zinad O.

Table 6: Physical properties of WCP, NCP and GBFS

Property	WCP	NCP	GBFS	Specification
Surface area (m ² /g)	420	-----	370	ASTM C204
Retained on sieve size 325 (45 μm)	0.012	0	0.085	-
Solubility in / Miscibility with Water	Soluble	Soluble	Soluble	-
Specific gravity	0.185	1.6	2.54	ASTM C188
activity index 28 days (%)	87	95	80	ASTM C618

Source: This test was conducted by author at Northern Technical University, Iraq

3.2. Mixing and casting of concrete

In this study, two mix formulations of mortar,- including the control mixture, were prepared with water-to-binder ratios of 0.3 and 0.45. To prepare the mortar specimens, cast iron mortar molds had been used, containing cubes and prisms. The molds used for casting mortar specimens for the compressive strength test, shown in Figure 4 were cube molds, having dimensions of 50x50x50 mm. The prism molds having dimensions of 40x40x160 mm were used for casting mortar specimens for the flexural strength test, density test, and water absorption. After casting all the test specimens, they were stored at room temperature and then de-molded after 24 h, and placed into a water-curing tank with a temperature of 24-34 °C according to ASTM C192, until the time of testing. For each trial mix, three specimens were cast for 7 days.



Figure 4: Molds and specimens
Source: Infographic by Zinad O.

4. Result and discussion

By using molds to cast concrete, after 28 day the concrete strength gained an acceptable limit of compressive strength (25 MPa) C25 in both cases.

To produce 1 m³ of conventional **concrete** C25 with a mix proportion of 1: 2.75 : 0.5 (cement : sand : water) the followings are needed (Ban & Ramli, 2010):

- 1) cement → 592 kg for 1 m³ of concrete mortar. The cost of necessary cement is 72\$/m³.
- 2) sand → 1628 kg for 1 m³ of concrete mortar. The cost of necessary sand is 13 \$/m³.
- 3) water → 300 kg for 1 m³ of concrete mortar. The cost of necessary water is 1 \$/m³.
- 4) labor fee: the cost of the mixing process for 1 m³ concrete mortar costs approximately 14 \$

The total cost is equal to approximately 100 \$/m³ concrete

To produce 1 m³ **sustainable mortar concrete** C25 with mixing proportion 0.475 : 0.25 : 0.25 : 2.75 : 0.025 : 0.5 (cement : WCP : BFS : sand : NGB : water) the followings are needed (Ban & Ramli, 2010):

- 1) cement → 281 kg for 1 m³ of concrete mortar. The cost of necessary cement is 33\$ / m³.
- 2) WCP → 148 kg for 1 m³ of concrete mortar. The cost of necessary WCP is 1\$ / m³.
- 3) BFS → 148 kg for 1 m³ of concrete mortar. The cost of necessary of BFS is 1\$ / m³.
- 4) NGB → 15 g for 1 m³ of concrete mortar. There is difference between NC and SC in their workability, which was improved by adding nanoparticles. The cost of necessary NGB is 3\$ / m³.
- 5) sand → 1628 kg for 1 m³ of concrete mortar. The cost of necessary sand is 13\$ / m³.
- 6) water → 300 kg for 1 m³ of concrete mortar. The cost of necessary water is 1\$ / m³.
- 7) labor fee: the cost of mixing process for 1 m³ sustainable concrete is approximately 10\$

The **total** cost of 1 m³ Sustainable mortar concrete is equal to approximately 62 \$

Table 7: Concrete cost analysis

Materials	Normal Concrete \$/m ³	Sustainable Concrete \$/ m ³
Cement	72	33
Sand	13	13
Water	1	1
Labor fee	14	10
WCP	-	1
BFS	-	1
NGB	-	3
TOTAL COST IN US DOLLAR \$ / 1 M³	100	62

Source: Own editing

5. Conclusion

This study suggests a more sustainable construction practice by substituting the environmentally weak cement with recycled construction waste-based materials, like WCP, BFS or NGB and reducing both the raw material need and the cost of concrete, thus the principle of a more sustainable green construction is achieved.

When it comes to the comparison of the mechanical properties, normal concrete and sustainable concrete perform equally good (Dawood et al., 2020), but there is an advantage around 40 % in their cost, in favor of the sustainable concrete. It is cheaper, more environment friendly but has equally good mechanical properties.

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