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The Effect of Nano Technology on the Properties of Sustainable Foam Concrete

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ABSTRACT

The worldwide construction industry has recognized the necessity for lightweight building materials that are flexible, high-performance, and environmentally friendly. In response to this need, lightweight foamed concrete (LFC) is being proposed. In concrete, nanoparticles are utilized for their beneficial effects, such as their small particle size and high reactivity, which improve the strength of concrete. In this study, foam concrete block waste was used as a partial substitute for cement in the manufacture of foamed concrete. The experimental program was done by preparing finally ground foam concrete wastes by using specific machines to produce particles similar to cement particles. The replacement ratios are (0, 10, 20, and 30) % by weight of cement and the TiO_2 ratio was 0.5% for all mixes. The mechanical properties, including compressive and tensile splitting strength, were examined at 7 and 28 days. Results indicate that FCBW decreases mechanical and durability properties due to increased porosity and reduced cement content at higher replacement levels. The findings show that adding more FCBW lowers compressive and tensile strengths, while mixes M1 and M2 keep strength ratios near the reference mix. However, a mix containing 10% FCBW and 0.5% nano-TiO_2 offers a promising mechanical performance.

Keywords Foam concrete, Nano-materials, Compressive strength.

1. INTRODUCTION

One ton of carbon dioxide (CO_2) is released during the production of one ton of clinker in cement manufacturing; this accounts for 7% of global CO_2 releases **(Hardjito and Rangan, 2005; Bisrya et al., 2015; Muhsin and Fawzi, 2021a)**. The decrease of carbon dioxide released in the manufacturing of cement and the increase in recycling the wastes of industries play a significant part in the pollution of the environment. The goal can be reached by using a mixture of materials that are sustainable in the projects of civil engineering

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(Muhsin and Fawzi, 2021b; Hussin and Aljalawi, 2022). Foam concrete (FC), also known as cellular concrete, is a mixture of mortar or cement paste that intentionally traps air voids **(Shah et al., 2021)**. Foam concrete is characterized by its lightweight, highness of flowability, minimal use of aggregates, controlled low strength, and excellent thermal insulation properties **(Amran et al., 2015).** Foam concrete can be produced with a wide range of densities (400–1850 kg/m^3) for various applications, including structural, partition, insulation and filling uses **(Raj et al., 2019)**. Humans have been interested in low self-weight and heat-isolating materials that were used in the past in Iraq, where history began. People utilized various forms of plant and wood piles, including mud or plaster mixed with rice husk and straw **(Jssem and Fawzi, 2024; Hnaihen, 2020)**. Foam concrete can be used in various building constructions. In the last 15 years, significant advancements have been made in foamed concrete production techniques **(Brdy et al., 2001).** Foam concrete has distinct properties that set it apart, including low weight, fluidity, thermal insulation qualities, and effective acoustic. It can be produced by mixing stable foam. The foaming agent solution was created separately by introducing air into it with a slurry **(Zho et al., 2015).** As stated by the numerous studies on the materials conducted so far, the pore structure and mechanical properties (density, water absorption, modulus of elasticity) of foam concrete can be significantly affected by the performance of the foam **(Hajimohamadi et al., 2018; Hussin and Aljalawi, 2022).** Also, utilizing remanufactured foam or surfactants can form a permeable microstructure in the concrete mixture, enabling air bubbles to be trapped. This process is known as Cellular Lightweight Concrete construction **(Jain et al., 2019).** Foamed concrete, like regular concrete, requires cement and sand for production, which raises concerns about sustainability and environmental impact **(Gau et al., 2015; Momin et al., 2020).** Substituting cement and sand with alternative materials can help address the stated matters and shift the building industry towards sustainability. Utilizing waste materials as substitutes for traditional concrete components like cement and sand is a widely used approach in this context **(Mo et al., 2016; Thomas, 2018).** Such waste is abundantly accessible worldwide, including industrial, agricultural, municipal, and building industry waste. The traditional methods for managing waste involve either dumping it or recycling it. Dumping waste through landfills or incineration is expensive, and it also poses environmental and health risks. Landfills can generate liquid waste, and very risky gas, all of which can have an impact on the surface vegetation and contribute to greenhouse gas emissions. Whereas the incineration method causes gas pollutants, which are detrimental to the environment **(Abdl-shafy and Mansur, 2018; Babfemi et al., 2018; Feronato and Torreta, 2019).** Nanotechnology is a vital field of science involving manipulating and creating nanometer-scale materials. Nanomaterials are materials in which at least one dimension of the atoms or molecules is less than 100 nm in size **(Mahdy, 2016)**. Nanoparticles have demonstrated their efficiency of these substances in various fields is attributed to their unique chemical and physical characteristics. **(Hasen and Tuama, 2023).** Nanoparticles can be categorized based on their size, shape, composition, consistency, and tendency to clump together **(Chokkareddy and Redhi, 2018).** Moreover, substances can be primarily classified as organic or non-organic. Nanoparticles have demonstrated their effectiveness in diverse fields due to their unique chemical and physical characteristics. Consequently, nanotechnology holds promise as a valuable tool to address the challenges and offer necessary support in various applications. Designing and developing new and innovative material properties at the nanoscale will pave the way for new applications and solutions **(Kianfar et al., 2020).** Nanoparticles have garnered increasing attention in recent

years, and various types have been incorporated into concrete mixtures to enhance both the mechanical and physical properties of concrete **(Salab and Assistant, 2016).**
In this study, nano titanium dioxide (TiO_2) will be used to study its effect on the mechanical properties (compressive and tensile strength) and durability properties (sorptivity and carbonation) of foamed concrete containing partial cement replacement ratios of finely ground foam concrete blocks.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Cement

OPC (CEM I, 42.5R) by Iraqi standards. **(IQS No.5, 2019)** was utilized. **Tables 1 and 2** show chemical and physical components.

Table 1. Cement chemical composition.

Oxide Composition	**wt%**	**Limits of (IQS No.5, 2019)**
Lime (CaO)	63.32	-----
Iron Oxide (Fe_2O_3)	4.16	-----
Alumina (AL_2O_3)	5.22	-----
Silica (SiO_2)	19.84	-----
insoluble residue(IR)	0.63	max (1.5)
Magnisum oxide(MgO)	2.81	max (5)
loss of ignition(loI)	2.77	max (4)
sulfate(SO_3)	2.39	2.8 if C3A>3.5 2.5 if C3A≤3.5
*Main Compounds of Cement		
Titra calcium C3S	58.84	---
dicalcium silicateC2S	13.2	---
tricalcium aluminateC3A	6.7	---
Tetracalcium aluminate-FferriteC4AF	12.91	

Table 2. Physical characteristics of the (OPC).

Propriety	**Test Results**	**Limits of (IQS No.5, 2019)**
The soundness using autoclave (%)	0.16	≤ 0.80
Initial setting(Vicat's approach)	131 min	≥ 45 min
Final setting(Vicat's method)	259 min	≤ 600min
Comp. Strength (MPa)		
Comp. Strength (2) days	26	≥20
Comp. Strength (28) days	46	≥ 42.5

2.1.2 Fine Aggregates

The concrete mixes used natural sand as fine aggregates. The physical and chemical properties of the fine aggregates are presented in **Table 3.** The test results show that the sand grading falls within the limits set by the **(IQS No.45, 2019)** and is categorized in zone 4.

Table 3. Fine aggregate sieve analysis.

Sieve number	Passing accumulative%	(IQS) zone four
10	100	100
4.75	95	89_100
3	83	74_100
1.18	67	54_90
0.6	55	34_59
0.3	13	7_30
0.15	4	0_10

2.1.3 Foaming Agent

Foaming agent for cellular concrete, confirming the American Society of Testing Materials requirements **(ASTM C796-97, 1997)** was utilized to produce LWC by entraining a controlled amount of air bubbles into the concrete mix. The foaming agent used in this study is protein-based.

2.1.4 Water

The water used for the mixes is confirmed **(IQS 1703, 2018)**

2.1.5 Foam Concrete Block Waste

The process of crushing foam concrete block waste involves three stages to achieve the desired particle size. Firstly, the waste is manually crushed by hand to break the larger portions of the waste into smaller, more manageable pieces. This prepares the material for further mechanical processing. Secondly, the partially crushed waste is subjected to the Los Angeles machine, which applies rotational impact and abrasion forces to further reduce the material's particle size, ensuring a more uniform size distribution. Finally, in the third stage, the material is passed through a ring mill for finer crushing, producing a consistent and well-graded particle size suitable for use as a partial cement replacement.

2.1.6 Nano Titanium Dioxide

A white powder of nano-TiO_2 in an amorphous form with an average particle size of 20 nm, and a specific surface area of 122.17 m^2 /g. shows the nano titanium dioxide used in this study. (0.5%) by cement weight of nano-Tio_2 was added; this ratio was implemented to avoid increasing costs.

2.2 Mix Proportions

The mixes were created with a wet density of 1000 kg/m^3 and a dry density of 900 kg/m^3. The water-binder ratio was 0.45, and the sand-binder ratio was 1:1.3. Four mixes were made with different amounts (0%, 10%, 20% and 30%) of foam concrete block waste (FCBW) used as a partial substitution for cement to find the best amount of cement replacement. Additionally, nano-Tio_2 materials were added at a ratio of 0.5% by weight of the cement to enhance the properties of the foam concrete.

2.3 Mixing Procedure and Curing

Mixing was done using a power-driven paddle mixer with a maximum capacity of 0.25m^3 and a speed of 40 rpm. To prepare the preformed foam, the foaming agent is diluted in water. Before mixing, the diluted mixture is aerated using a port foam foaming machine to produce stable foam with a density of 68 kg/m^3. The base mortar mix is prepared by combining the binder, filler materials, and water with the nano-titanium dosage. Water is gradually added to the mix until the desired consistency is reached, following the technique from **(Al-Mulali, 2015).** The foam quantity is calculated and added gradually to the base mix until a homogeneous foamed concrete mix is obtained with a wet density of 1000kg/m^3 ±3%. The density of the foamed concrete mixture is determined by weighing a one-liter cup of the fresh mix. Once the required plastic density is achieved, the foamed concrete is poured into the molds. The molds have been coated with vegetable oil to prevent any reaction with the foamed concrete. Subsequently, the samples are covered in plastic sheets to avoid moisture loss and left to dry for 24 hours. After the foamed concrete samples are hardened, they are removed from the molds, weighed, and then wrapped with plastic cling film until the testing age **(Jones and McCarthy, 2005).** The foam concrete mix constituents are shown in **Table 5**.

Table 5. Foamed concrete mix constituents

Mix	Replacement Ratio (by Weight)	TiO_2 addition Ratio (by Weight)	Cement (kg/m^3)	Foam Block waste (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Mc	0	0	365	0	475	165
M1	10%	0.5%	329	36	475	165
M2	20%	0.5%	292	73	475	165
M3	30%	0.5%	329	36	475	165

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

This test was conducted on 100×100×100mm cubes using a compression test machine with a loading rate of 0.1 kN/s according to **(BS EN 12390-3, 2009a).** The average of three cubes was recorded for each test conducted at ages 7 and 28, as shown in **Fig.1.** The results are shown in **Fig. 2.**

Figure 1. The test of compressive strength.

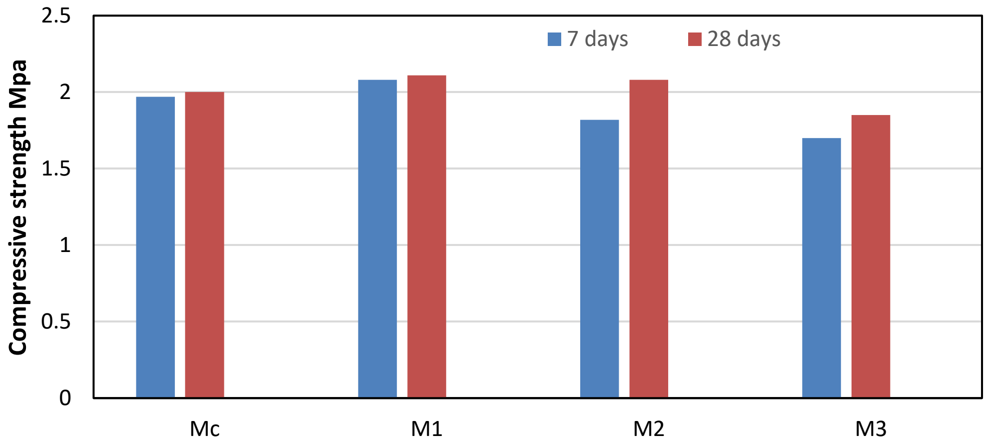

Figure 2. Compressive strength at 7 and 28 days

The use of (FCBW) impacts compressive strength depending on the replacement ratio. At lower replacement levels, the reduction in compressive strength is minimal due to the filler effect of the waste material. However, at higher replacement ratios, the compressive strength decreases more significantly due to the lower reactivity of the waste compared to cement.

3.2 Splitting Tensile Strength Test

The tensile strength test was performed according to which 150×300mm cylindrical specimens were used. They were tested using an electrical testing machine. This test was conducted at 7 and 28 days as shown in **Fig. 3.** By **(BS EN 12390-6, 2009b).** The results are shown in **Fig. 4.**

Figure 3. The test of splitting tensile strength

(FCBW) as a partial cement replacement affects the tensile strength of foam concrete depending on the replacement ratio. Lower replacement levels have minimal impact on tensile strength due to the filler effect, while higher ratios cause a noticeable decrease in tensile strength, attributed to reduced cohesion and weaker bond strength in the matrix. Optimal replacement ratios are necessary to maintain adequate tensile performance. Nano-titanium dioxide significantly improves the tensile strength of foam concrete by enhancing the matrix microstructure and bridging microcracks. Its ability to improve the interfacial transition zone and refine pore distribution leads to greater resistance to tensile forces, making it an effective additive for enhancing foam concrete mechanical properties in tension-related related.

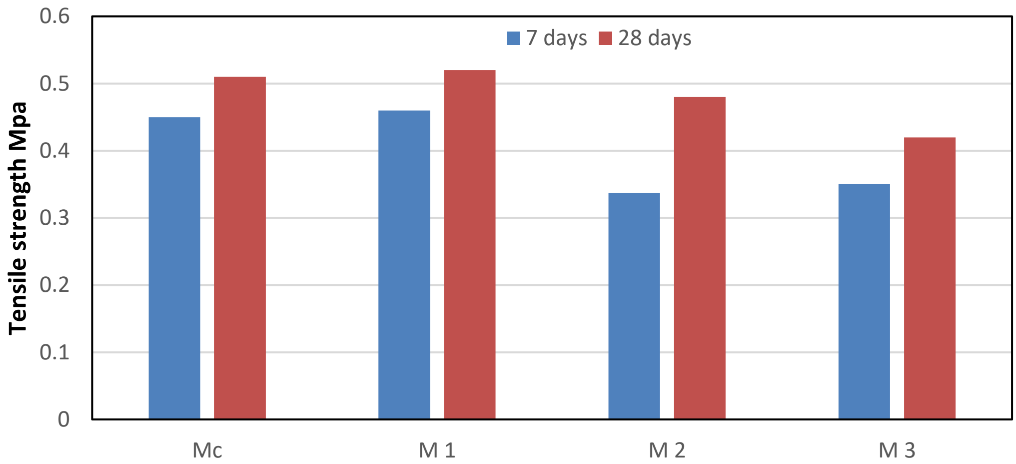

Figure 4. Splitting tensile strength at 7 and 28 days

3.3 Sorptivity

The sorptivity test was conducted at the age of 28 days. **Fig. 5.** shows the readings achieved for the four foamed concrete mixes. The figure shows that showed that sorptivity reading increases with the increase of FCBW replacement levels, This means that the water intake through the face immersed in water was too slow to be taken by the capillary pores. This test was conducted By **(ASTM C1585-13, 2013).**

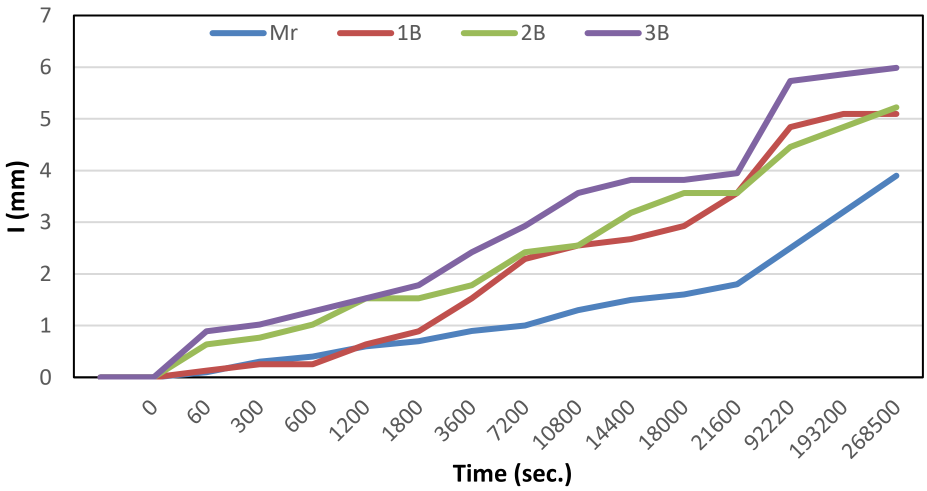

Figure 5. Sorptivity (mm) at 28 days.

4. CONCLUSIONS

The present study explores the possibility of using waste from foam concrete blocks as a substitute for cement in foamed concrete mixes. This substitution has demonstrated significant potential for reducing energy consumption and costs in the production of foam concrete. Furthermore, utilizing these waste blocks for foam concrete production is more environmentally friendly compared to traditional concrete production. The compressive and tensile splitting strengths decreased as the waste content increased. The mix with a 10% replacement level showed a 5% lower strength compared to the control mix, while the mix with a 20% replacement level showed a 10% lower strength. As age increased, the compressive and tensile splitting strengths increased. Higher FCBW content results in increased sorptivity readings. It appears that a greater FCBW content disrupts the pore structure of the foamed concrete mix, thereby forming continuous pores. That's led to the durability decrease with the increase of replacement ratios. Adding 0.5% Nano-Tio_2 enhances both compressive and tensile strength, demonstrating beneficial effects due to their small particle size and high reactivity. A mix containing 10% FCBW and 0.5% nano-TiO_2 offers a promising mechanical performance.

The following points are some of the recommendations:

1- Investigate the possibility of partially replacing both cement and sand with FCBW in creating environmentally friendly foam concrete.
2- Assess the cost-effectiveness of producing foam concrete with nano TiO_2 at an industrial scale.
3- Study the effects of FCBW and nano-TiO_2 on additional properties such as thermal conductivity, acoustic insulation, and fire resistance.

Credit Authorship Contribution Statement

Ban Abdulkarim Salman: Writing – review & editing, Writing – original draft. Mohammed Zuhear Al-Mulali: Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abdel-shafy, H.I. and Mansour, M.S.M., 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, 27(4), pp. 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Al-Mulali, M., 2015. Investigating the effect of unground OPA incorporation as a partial cement replacement on the properties of foam concrete. PhD thesis, Department of Building Technology, School of Housing, Building and Planning, University Sains Malaysia

Amran, Y. H. M., Farzadnia, N.and Abang , A. A. 2015. Properties and applications of foamed concrete: A review. *Construction and Building Materials*, 101, pp. 990-1005. https://doi.org/10.1016/j.conbuildmat.2015.10.112

ASTM C796–97,1997. Standard test method for foaming agents for use in producing cellular concrete using preformed foam. https://doi.org/10.1520/C0796-97

ASTM C1585-13, 2013. Standard test method for measurement of rate of absorption of Water by hydraulic-cement concrete.

Babafemi, A. J., Šavija, B., Paul, S. C. and Anggraini, V., 2018. Engineering properties of concrete with waste recycled plastic: A review. *Sustainability*, 10(11). https://doi.org/10.3390/su10113875.

Bisarya, A., Chouhan, R., Mudgal, M., and Amritphale, S., 2015. Fly ash based geopolymer concrete: A new technology towards the greener environment: A review. *International Journal of Innovative Research in Science, Engineering, and Technology*, 4(12).

Brady, K.C., Watts, G.R.A. and Jones, M.R., 2001. Specification for foamed concrete. *Crowthorne, UK: TRL Limited*.

BS EN 12390-3, 2009a. Compressive strength of test specimens.

BS EN 12390-6, 2009b. Tensile splitting strength of test specimens.

Chokkareddy, R. R. and Redhi, G., 2018. Green synthesis of metal nanoparticles and its reaction mechanisms: Synthesis, characterization and their applications. *In The Macabresque: Human Violation and Hate in Genocide, Mass Atrocity and Enemy-Making*, pp. 113-139. https://doi.org/10.1002/9781119418900.ch4

Ferronato, N. and Torretta, V. ,2019. Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health*, 16(6), 1060. https://doi.org/10.3390/ijerph16061060.

Gau, T., Shen, L., Shen, M., Chen, F., Liu, L. and Gao, L., 2015. Analysis on differences of carbon dioxide emission from cement production and their major determinants*. Journal of Cleaner Production*.103, pp. 160–170. https://doi.org/10.1016/j.jclepro.2014.11.026.

Hajimohammadi, A., Ngo, T. and Mendis, P., 2018. Enhancing the strength of pre-made foams for foam concrete applications. *Cement and Concrete Composites*. 87, pp. 164-171. https://doi.org/10.1016/j.cemconcomp.2017.12.014

Hardjito, D. and Rangan, B.V., 2005. *Development and properties of low-calcium fly ash-based geopolymer concrete.* Research Report GC 1, Faculty of Engineering, Curtin University of Technology, Perth, Australia.

Hasen, H.M. and Tuama, R.J., 2023. Review about the applications of nanoparticles in batteries*. Journal of Engineering,* 29(8), pp. 47–60. https://doi.org/10.31026/j.eng.2023.08.04

Hnaihen, K. H., 2020. The appearance of bricks in ancient Mesopotamia. *Athens Journal of History*, 6(1), pp. 73-96. https://doi.org/10.30958/ajhis.6-1-4

Hussian, Z.A., and Aljalawi, N.M.F, 2022. Some properties of reactive powder concrete contain recycled glass powder. *Journal of Engineering*, 28(10), pp. 42-56. https://doi.org/10.31026/j.eng.2022.10.04

IQS No. 45, 2019. Aggregate from Natural Sources for Concrete and Construction.

IQS No.1703, 2018. Used Water in Concrete.

IQS No.5, 2019. Portland Cement. The Central Organization for Standardization and Quality Control. Iraqi Specification

Jain, D., Hindoriya, A.K., and Bhadauria, S.S., 2019. Evaluation of properties of cellular lightweight concrete*. In AIP Conference Proceedings*, 2158(1). AIP Publishing. https://doi.org/10.1063/1.5127158

Jones, M.R., and Mccarthy, 2005. Preliminary views on the potential of foamed concrete as a structural material. *Magazine of Concrete Research*. 57(1), pp. 21-31. https://doi.org/10.1680/macr.2005.57.1.21

Jssem, M., and Fawzi, N.M., 2024. Effect of expanded perlite aggregate and silica fume on some properties of lightweight concrete. *Journal of Engineering,*30(5), pp. 172–185. https://doi.org/10.31026/j.eng.2024.05.11 .

Kianfar, E., 2020. Introducing the application of nanotechnology in lithium-ion battery. *In J. Smith and R. Brown,* Advances in nanotechnology, pp. 45-67.

Mahdy, S., 2016. Microbicidal effect of Fe_2O_3 nanoparticles in antimicrobial agent system*. Journal of Engineering*, 22(10), pp. 52-61. https://doi.org/10.31026/j.eng.2016.10.04

Mo, K.H., Alengaram, U.J., Jumaat, M.Z., Yap, S. P., and Lee, S. C. ,2016. Green concrete partially comprised of farming waste residues: A review. *Journal of Cleaner Production*, 117, pp. 122-138. https://doi.org/10.1016/j.jclepro.2016.01.022.

Moumin, G., Ryssel, M., Zhao, L., Markewitz, P., Sattler, C., Robinius, M., and Stolten, D. ,2020. CO2 emission reduction in the cement industry by using a solar calciner.*Renewable Energy*. 145, pp. 1578-1596. https://doi.org/10.1016/j.renene.2019.07.045

Muhsin, Z.F., and Fawzi, N.M., 2021a. Effect of Nano Calcium Carbonate on Some Properties of Reactive Powder Concrete. In *IOP Conference Series: Earth and Environmental Science* 856(1). IOP Publishing. http://dx.doi.org/10.1088/1755-1315/856/1/012026

Muhsin, Z.F., and Fawzi, N.M., 2021 b. Effect of fly ash on some properties of reactive powder concrete. *Journal of Engineering*, *27*(11), pp. 32-46. https://doi.org/10.31026/j.eng.2021.11.03

Mansouri, I., and Esmaeili, E. 2016. Nanotechnology applications in the construction industry. In A. Johnson & B. Miller. *Innovations in construction technology*, pp. 111-140. IGI Global. https://doi.org/10.4018/978-1-5225-0344-6.ch004

Raj, A., Sathyan, D., and Mini, K.M., 2019. Physical and functional characteristics of foam concrete: a review*. Constr. Build. Mater*, 221, pp. 787–799. https://doi.org/10.1016/j.conbuildmat.2019.06.052

Salab, M., Shaker, S., and Salim, K. ,2016. Preparation and study of morphological properties of ZnO nanopowder. *Journal of Engineering*, 22(4), pp. 116–126. https://doi.org/10.31026/j.eng.2016.04.08

Shah, S.N., Mo, K.H., Yap, S.P., Yang, J., and Ling, T.C., 2021. Lightweight foamed concrete as a promising avenue for incorporating waste materials: A review. *Resources, Conservation and Recycling*, 164, 105103. https://doi.org/10.1016/j.resconrec.2020.105103

Thomas, B.S., 2018. Green concrete partially comprised of rice husk ash as a supplementary cementitious material – a comprehensive review. *Renewable and Sustainable Energy Reviews*. 82, pp. 3913–3923. https://doi.org/10.1016/j.rser.2017.10.081.

Zhao, X., Lim, S.K., Tan, C.S., Li, B., Ling, T.C., Huang, R., and Wang, Q., 2015. Properties of foamed mortar prepared with granulated blast-furnace slag. *Materials*, 8(2), pp. 462–473. https://doi.org/10.3390/ma8020462

تاثير التيتانيوم النانوي على الخرسانة الرغوية المستدامة

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الخلاصة

لقد أدركت صناعة البناء والتشييد في جميع أنحاء العالم ضرورة وجود مواد بناء خفيفة الوزن ومرنة وعالية الأداء وصديقة للبيئة. ومع الأخذ في الاعتبار هذه الحاجة، يتم استخدام الخرسانة الرغوية خفيفة الوزن (LFC). في الخرسانة، يتم استخدام الجسيمات النانوية لتأثيراتها المفيدة، مثل حجمها الصغير وتفاعلها العالي، مما يحسن قوة الخرسانة. في هذه الدراسة تم استخدام مخلفات البلوك الخرساني الرغوي كبديل جزئي للأسمنت لإنتاج الخرسانة الرغوية. تم تنفيذ البرنامج التجريبي من خلال تحضير مخلفات الخرسانة الرغوية المطحونة نهائياً باستخدام آلات خاصة لإنتاج جسيم مماثل لحجم جسيم الأسمنت. وكانت مستويات الإحلال (0,10,20,30) % وزناً للأسمنت وكانت نسبة 0.5% TiO_2 لجميع الخلطات. تم فحص الخواص الميكانيكية بما في ذلك مقاومة الانضغاط والشد عند عمر 7، 28 يوما. تشير النتائج إلى أن FCBW يقلل من الخواص الميكانيكية والمتانة بسبب زيادة المسامية وانخفاض محتوى الأسمنت عند مستويات الإحلال الأعلى. تظهر النتائج أن إضافة المزيد من FCBW يقلل من قوة الضغط والشد، بينما يحافظ المزيج M1 و M2 على نسب القوة بالقرب من المزيج المرجعي. لكن، . يقدم المزيج الذي يحتوي على 10% FCBW و 0.5% nano-TiO_2 أداءً ميكانيكيًا واعدًا.

الكلمات المفتاحية: الخرسانة الرغوية، المواد النانوية، مقاومة الانضغاط .