

Effect of Calcined Clay as a Substitution for Cement on the Fresh and Hardened Properties of Concrete

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ABSTRACT

Over the previous several years, investigation has become more concentrated on environmentally friendly, economical, and socially beneficial substitutes for concrete production. Alternatives include industrial waste, the prospective benefits of which are potentially addressed via recycling, reusing, and innovative approaches. The usage of these wastes as alternative constituents may provide significant energy savings and an overall decrease in Portland cement (PC) usage, thereby leading to a lowering of carbon dioxide (CO₂) emissions. Thus, the inclusion of calcined clay (CC) as a cementitious component in concrete can mitigate the environmental impact and decrease the quantity of Portland cement (PC) in mixtures. This research examines concrete including 0%, to 20% of CC as cementitious components. The primary aims of this investigation are to assess the impact of CC as cementitious components on both fresh and hardened concrete. An overall of 45 samples of concrete were utilised to evaluate water absorption, density, and compressive strength of the concrete, respectively. Furthermore, whenever the quantity of CC in the combination increases, the workability, density, and water absorption of green concrete diminish. The compressive strength increases by 37.20 MPa at 10% CC for 28 days. The use of 10% CC in construction has been suggested to provide optimal results for the building sector in Civil Engineering.

KEYWORDS: Calcined Clay, Concrete, Workability, Density, Water absorption, Compressive Strength.

INTRODUCTION

Concrete is nowadays the second greatest commonly utilised material internationally, mostly in the building engineering [1]. Concrete is broadly utilised because of its versatility, durability, and accessibility [2]. Concrete is frequently employed in construction due to the rapid advancement of superstructures such as high-rise buildings, dams, bridges, and marine foundations [3]. In other terms, more robust concrete comprises a high Portland cement (PC) than less durable concrete. Thus, the augmented utilisation of concrete elevates the requirement for PC. Nonetheless, concrete generates carbon discharges due to PC [4, 5], which contributes significantly to environmental concerns associated with construction practices.

The manufacture of cement entails several disadvantages, like elevated manufacturing expenses and considerable energy usage. Significant amounts of CO₂ as well as other atmospheric gases are generated through the PC production [6-8]. During the production of one tonne of PC, around 1 tonne of CO₂ are emitted into the environment, and around 1.60 megawatt-hours of energy is required to produce 1.0 tonne of PC [9]. The PC manufacture is regarded as an expensive and environmentally sustainable process [10]. Moreover, cement production has resulted in environmental repercussions, contributing about 7 to 10 per cent of global CO₂ emissions [11, 12]. Global warming and rising temperatures result from the emission of greenhouse gases [13, 14]. Furthermore, the heightened utilisation of naturally occurring resources for cement manufacturing results in ecosystem degradation [2]. The use of waste products and unused components as SCMs aims to mitigate these two significant issues [15]. The use of agro/industrial wastes such as marble powder [16-18], fly ash [19-21], waste glass [22, 23], corn cob ash [24, 25], silica fume [26, 27], millet husk ash [28-31], metakaolin [32-35], wheat straw ash [36-38], and calcined clay (CC) in concrete. Therefore, this research examines the usage of calcined clay (CC) as SCMs in concrete. Clay is a widely obtainable, cost-effective, and easily accessible material. Concurrently, it is a substance with diverse mineralogical structures, resulting in the publishing of several publications assessing the feasibility of consuming clays from precise deposits for the manufacture of SCM in calcination procedures [39, 40]. The scientific literature on activated states of clay constituent part and their usage in concrete is extensive and encompasses a wide range of subjects. This study focuses on the use of CC in concrete. The use of SCM, including as calcined clay, mitigates carbon emissions and conserves natural assets, particularly in poor countries. Clay is readily available in several regions globally and has significant pozzolanic properties when subjected to temperatures ranging from 700 to 850 degrees Celsius. It is a naturally occurring pozzolan with a decreased carbon footprint, capable of reducing greenhouse gas production by up to 30% [41]. The extensive use of CC might fulfil the increasing need for cement alternatives. It can promptly restore its microstructure and pore configuration due to its high reactivity as a pozzolan [42]. The integration of CC has been revealed to progress the hardened properties and endurance of concrete [43, 44]. Numerous studies indicate that CC substantially enhances both early and late-age hardness of concrete [43, 44]. The main purpose of this research study is performed on concrete comprising CC as SCM to find out the fresh, and hardened properties of concrete.

EXPERIMENTAL PROGRAM

Materials

Cement employed as a binding agent in this work. Calcined clay (CC) is clay subjected to high temperatures (often 700–850°C) by a process known as calcination. This heat process eliminates chemically bonded water and volatile organic molecules, irreversibly modifying the clay's mineral composition and characteristics. Following the calcination procedure, it was processed through a 75-micron mesh and then incorporated as a cementitious constituent in concrete. Furthermore, river sand was used as fine aggregates (FA), passing through a 4.75 mm mesh, whereas broken stone served as coarse aggregates (CA) measuring 20 mm in size. The consuming water used for this investigation was sourced from the research lab.

Mix Design

This research used concrete mixes with percentages of 0–20 % CC as a substitute for PC to identify the optimal CC combination. A mix ratio of 1:1.4:2.78 was used, accompanied by a w/c ratio of 0.50. Table 1 contains the data on mixture extents and the requisite quantities of ingredients for the making of 1 m³ of concrete for each mix proportion.

Table 1: Mix Design of CC based Concrete

Mix Proportions	Binding Material (%)		Amount of Concrete Constituents (kg/m ³)				
	PC	CC	PC	CC	FA	CA	Water
CC0	100	0	375	0	525	1043	188
CC5	95	5	356.25	18.75	525	1043	188
CC10	90	10	337.50	37.50	525	1043	188
CC15	85	15	318.75	56.25	525	1043	188
CC20	80	20	300	75	525	1043	188

Testing Procedures

The slump test was conducted on several green concrete with differing concentrations of CC as a supplementary cementitious material by applying the BS EN 12350-2 standard. Additionally, the density and water absorption were assessed for samples composed of concrete mixed with various amounts of CC as validated by BS EN 12390-7 and BS 1881 methodologies on 28 days. The compressive strength was achieved on a cubical sample of 100mm x 100mm x 100mm, including varying levels of substitution of Portland cement with CC by using BS EN 12390-3.

RESULTS AND DISCUSSION

Slump Test

It was evaluated the consistency of green concrete using CC as a SCM is illustrated in Figure 1. The optimal slump value obtained for the mix comprising 0% of CC is 58 mm, while the least slump value observed is 27 mm with 20% CC as a SCM in the combination. The use of CC in the combination seems to reduce the slump in concrete. The decline in performance is attributable to the greater specific surface area of CC particulates contrasted with PC, which absorb additional water as the proportion of CC in the concrete composition increases.

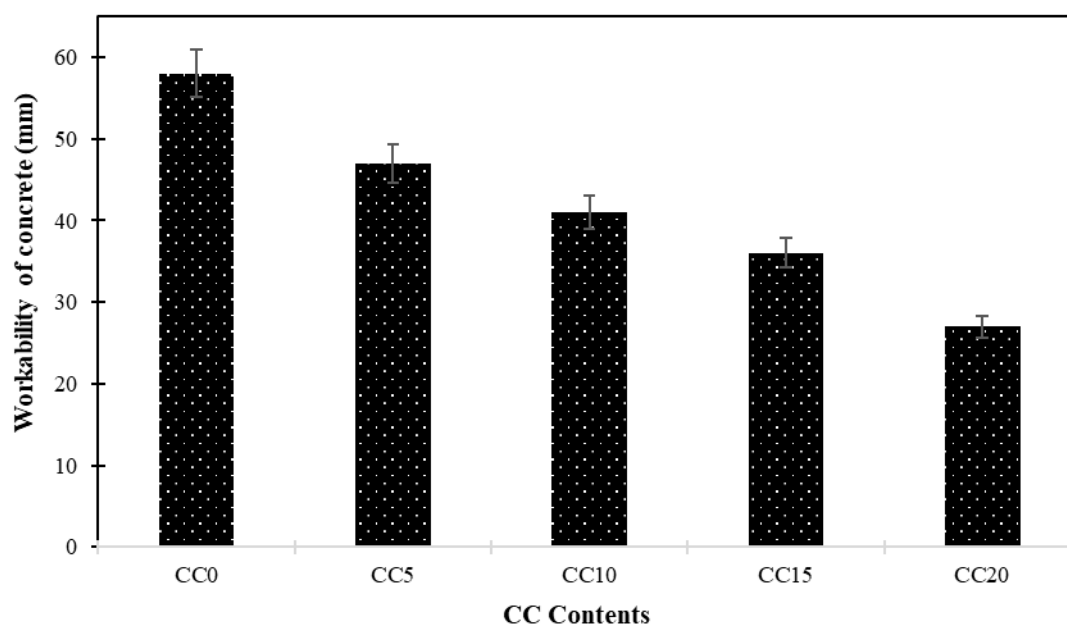


Figure 1: Workability of CC modified Concrete

Water Absorption (WA)

It was carried out on concrete comprising with CC as a SCM at 28 days as shown in Figure 2. The greatest WA recorded is 3.15% in the control mix, while the lowest possible amount is 2.08% in the concrete combination with 20% CC as SCM at 28 days. The outcomes show that the WA decreases with the integration of CC in the combination of concrete. The drop in WA is attributable to the smaller particle size of CC than that of PC, which occludes the residual microporosity left by the remaining concrete components as the proportion of CC in the combination rises.

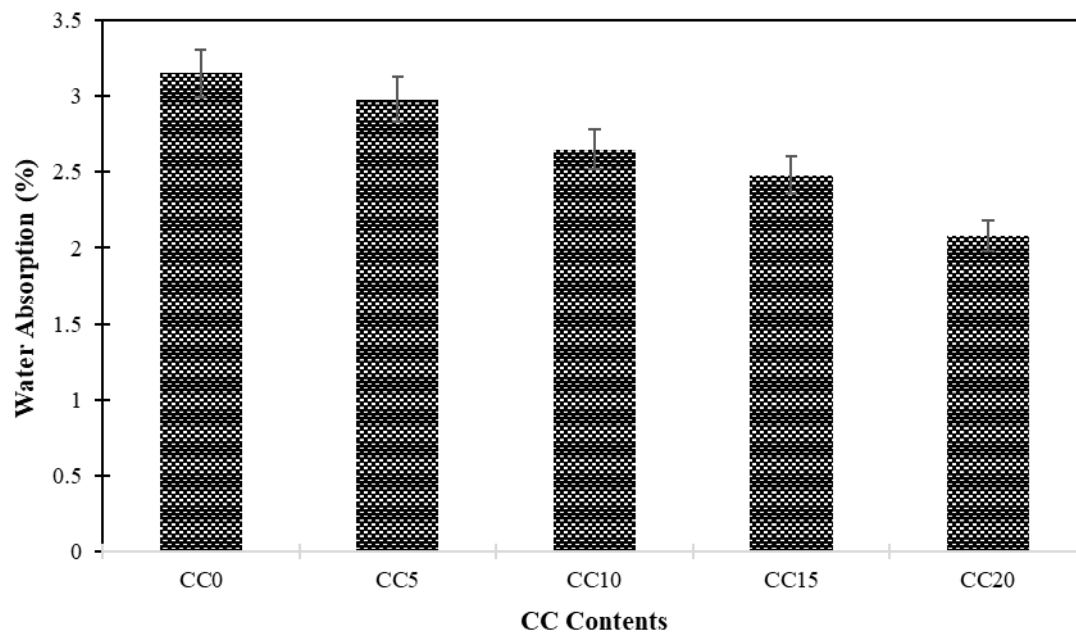


Figure 2: Water Absorption of CC modified Concrete

Dry Density

The density of concrete containing various concentrations of CC as a supplementary cementitious material, assessed on 28 days is exposed in Figure 3. The density of concrete measured at 5%, 10%, 15%, and 20% CC is 2310, 2290, 2278, and 2262 kg/m³, respectively, which is lesser than mixture without integration of CC. The density of concrete has significantly decreased as the doses of CC in the combination increase. The decline in density resulting from the specific gravity of CC is lesser to that of PC.

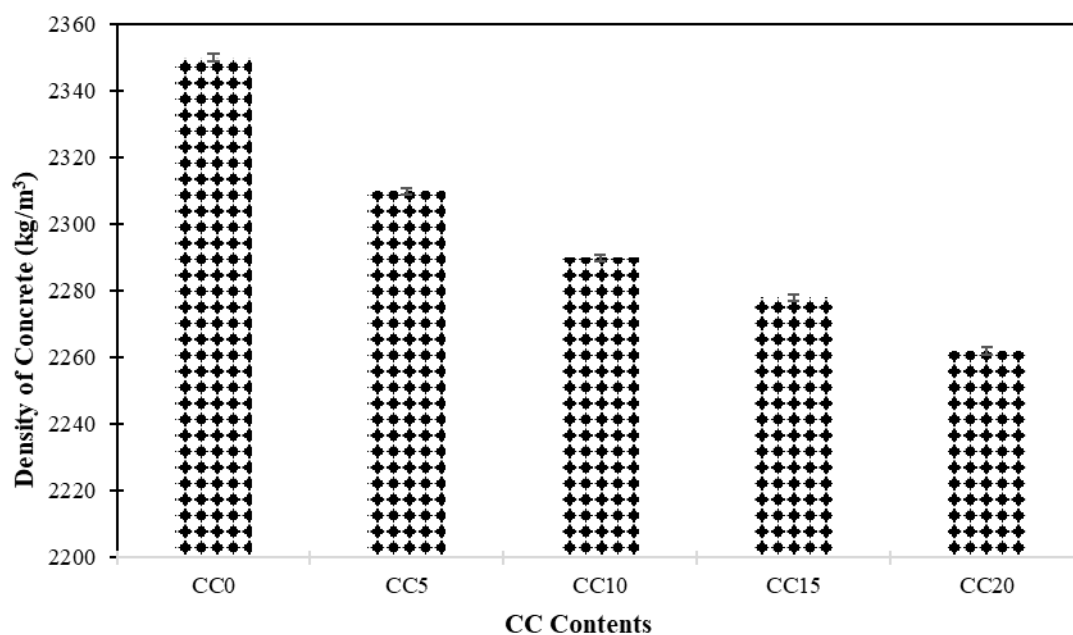


Figure 3: Dry Density of CC modified Concrete

Compressive Strength

The examination was conducted on cubic specimens composed of concrete with the incorporation of CC as a SCM, as seen in Figure 4. The maximum compressive strength is calculated at 37.20 MPa with 10% CC, while the minimum strength is noted at 22.50 MPa with 20% CC in composites on 28 days. The outcomes of the experiment indicated a rise in the strength of concrete comprising up to 10% of CC, accredited to the fineness of CC that filled the micropores left by the various concrete constituents. However, beyond this threshold, strength begins to decline due to the dilutive effect of CC on PC, which diminishes the pozzolanic interactions caused by the concrete components.

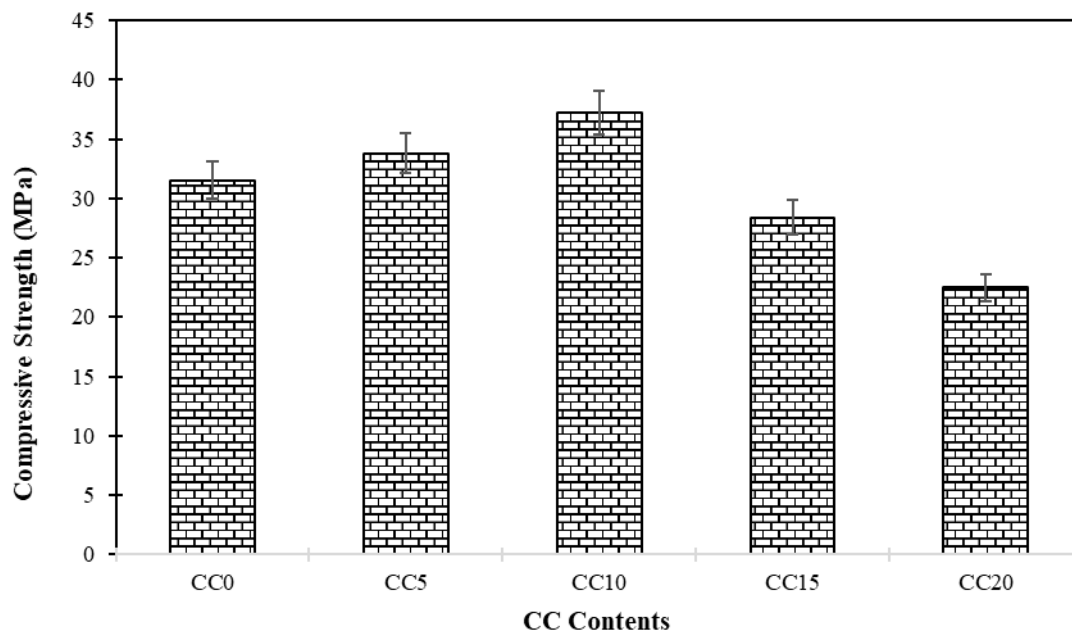


Figure 4: Compressive Strength of CC modified Concrete

CONCLUSIONS

The scientific assessment indicates that the integration of CC as SCM in concrete yields optimal outcomes for the building industry. The subsequent conclusions of this investigation are as follows:

- The inclusion of CC reduced workability for all samples compared to the combination with 0% of CC. The decline in workability is attributable to the increased WA of CC as a supplementary cementitious material compared to PC.
- The dry density and WA declines as the amount of CC rises in concrete.
- The maximum compressive strength is estimated at 37.20 MPa with 10% CC, while the minimum strength is noted at 22.50 MPa with 20% CC in concrete. Findings show an increase in the strength of concrete with the incorporation of up to 10% of CC, owing to the fineness of CC which seals the micropores in concrete.

- The outcomes of the test indicate that the use of 10% CC provides the maximum strength; hence, it is suggested for implementation in the construction sector.

References

- [1] P. Zhang, S. Han, G.L. Golewski, X. Wang, Nanoparticle-reinforced building materials with applications in civil engineering, *Adv. Mech. Eng.* 12 (2020).
- [2] A.A. Jhatial, W.I. Goh, A.K. Mastoi, A.F. Traore, M. Oad, Environmental assessment and mechanical properties of Polypropylene fibres reinforced ternary binder foamed concrete, *Environ. Sci. Pollut. Res.* 29 (2022) 2985–3007.
- [3] T.H. Wee, Y. Matsunaga, E. Sakai-, Y. Watanabe, O. Plant, Production and Properties of High Strength, *Cem. Concr. Res.* 25 (1995) 709–714.
- [4] A. Bahari, A. Sadeghi-Nik, F.U.A. Shaikh, A. Sadeghi-Nik, E. Cerro-Prada, E. Mirshafiei, M. Roodbari, Experimental studies on rheological, mechanical, and microstructure properties of self-compacting concrete containing perovskite nanomaterial, *Struct. Concr.* 23 (2022) 564–578.
- [5] R. Choudhary, R. Gupta, T. Alomayri, A. Jain, R. Nagar, Permeation, corrosion, and drying shrinkage assessment of self-compacting high strength concrete comprising waste marble slurry and fly ash, with silica fume, *Structures.* 33 (2021) 971–985.
- [6] Golewski, G.L., Green concrete based on quaternary binders with significant reduced of CO₂ emissions, *Energies.* 14 (2021) 4558.
- [7] S.H. Channa, S.A. Mangi, N. Bheel, F.A. Soomro, S.H. Khahro, Short-term analysis on the combined use of sugarcane bagasse ash and rice husk ash as supplementary cementitious material in concrete production, *Environ. Sci. Pollut. Res.* 29 (2022) 3555–3564.
- [8] M.A. Keerio, A. Saand, A. Kumar, N. Bheel, K. Ali, Effect of local metakaolin developed from natural material soorh and coal bottom ash on fresh, hardened properties and embodied carbon of self-compacting concrete, *Environ. Sci. Pollut. Res.* 28 (2021) 60000–60018.
- [9] N. Bheel, K.A. Kalhor, T.A. Memon, Z.U.Z. Lashari, M.A. Soomro, U.A. Memon, Use of Marble Powder and Tile Powder as Cementitious Materials in Concrete, *Eng. Technol. Appl. Sci. Res.* 10 (2020) 5448–5451.
- [10] A.M. Neville, “Properties of Concrete.” Pearson Education Asia Pte. Ltd., England, 14, 15, 35, 83, 191, and 192., 2000.
- [11] R.M. Andrew, Global CO₂ emissions from cement production, *Earth Syst. Sci. Data.* 10 (2018) 195–217.
- [12] J. Zhang, G. Liu, B. Chen, D. Song, J. Qi, X. Liu, Analysis of CO₂ Emission for the cement manufacturing with alternative raw materials: A LCA-based framework, *Energy Procedia.* 61 (2014) 2541–2545.
- [13] G.L. Golewski, Comparative measurements of fracture toughness combined with visual analysis of cracks propagation using the DIC technique of concretes based on cement matrix with a highly diversified composition, *Theor. Appl. Fract. Mech.* 121 (2022) 103553.
- [14] C. Sun, Q. Chen, J. Xiao, W. Liu, Utilization of waste concrete recycling

- materials in self-compacting concrete, *Resour. Conserv. Recycl.* 161 (2020).
- [15] T.F. Awolusi, A.O. Sojobi, J.O. Afolayan, SDA and laterite applications in concrete: Prospects and effects of elevated temperature, *Cogent Eng.* 4 (2017).
- [16] Bheel, N., Nadeem, G., Almaliki, A.H., Al-Sakkaf, Y.K., Dodo, Y.A. and Benjeddou, O., 2024. Effect of low carbon marble dust powder, silica fume, and rice husk ash as tertiary cementitious material on the mechanical properties and embodied carbon of concrete. *Sustainable Chemistry and Pharmacy*, 41, p.101734.
- [17] Bheel, N., Chohan, I.M., Alwetaishi, M., Waheeb, S.A. and Alkhatabi, L., 2024. Sustainability assessment and mechanical characteristics of high strength concrete blended with marble dust powder and wheat straw ash as cementitious materials by using RSM modelling. *Sustainable Chemistry and Pharmacy*, 39, p.101606.
- [18] Bheel, N., Benjeddou, O., Almujibah, H.R., Abbasi, S.A., Sohu, S., Ahmad, M. and Sabri, M.M.S., 2023. Effect of calcined clay and marble dust powder as cementitious material on the mechanical properties and embodied carbon of high strength concrete by using RSM-based modelling. *Heliyon*, 9(4).
- [19] Kumar, S., Bheel, N., Zardari, S., Alraeeini, A.S., Almaliki, A.H. and Benjeddou, O., 2024. Effect of graphene oxide on mechanical, deformation and drying shrinkage properties of concrete reinforced with fly ash as cementitious material by using RSM modelling. *Scientific Reports*, 14(1), p.18675.
- [20] Bheel, N., Awoyera, P., Shar, I.A. and Kirgiz, M.S., 2024. Self-compacting concrete blended with fly ash and ground granulated blast furnace slag. In *Advance upcycling of by-products in binder and binder-based materials* (pp. 309-334). Woodhead Publishing.
- [21] Bheel, N., Jokhio, M.A., Abbasi, J.A., Lashari, H.B., Qureshi, M.I. and Qureshi, A.S., 2020. Rice husk ash and fly ash effects on the mechanical properties of concrete. *Engineering, Technology & Applied Science Research*, 10(2), pp.5402-5405.
- [22] Baikerikar, A.V., Ganachari, V., Khed, V.C., Bheel, N., Alraeeini, A.S. and Almujibah, H., 2024. Synergistic effects of nano titanium dioxide and waste glass powder on the mechanical and durability properties of concrete. *Scientific Reports*, 14(1), p.27573.
- [23] Keerio, M.A., Abbasi, S.A., Kumar, A., Bheel, N., Rehaman, K.U. and Tashfeen, M., 2022. Effect of silica fume as cementitious material and waste glass as fine aggregate replacement constituent on selected properties of concrete. *Silicon*, 14(1), pp.165-176.
- [24] Bheel, N., Kumar, D., Ismail, F.I., Salilew, W.M., Alwetaishi, M., Waheeb, S.A. and Alkhatabi, L., 2024. Combined effect of jute fiber and corn cob ash on sustainability assessment and mechanical properties of roller compacted concrete using RSM modelling. *Scientific Reports*, 14(1), p.29724.
- [25] Bheel, N., Ali, M.O.A., Liu, Y., Tafsirojjaman, T., Awoyera, P., Sor, N.H. and Bendezu Romero, L.M., 2021. Utilization of corn cob ash as fine aggregate and ground granulated blast furnace slag as cementitious material in concrete. *Buildings*, 11(9), p.422.

- [26] Buller, A.S., Ali, M., Ali, T. and Bheel, N., 2024. Effect of silica fume on fracture analysis, durability performance and embodied carbon of fiber-reinforced self-healed concrete. *Theoretical and Applied Fracture Mechanics*, 130, p.104333.
- [27] Ja'e, I.A., bin Raja Sazrin, R.A.N., Syamsir, A., Bheel, N., Amaechi, C.V., Min, T.H. and Anggraini, V., 2024. Optimisation of mechanical properties and impact resistance of basalt fibre reinforced concrete containing silica fume: Experimental and response surface assessment. *Developments in the Built Environment*, 17, p.100368.
- [28] Bheel, N., Ali, M.O.A., Tafsirojjaman, Khahro, S.H. and Keerio, M.A., 2022. Experimental study on fresh, mechanical properties and embodied carbon of concrete blended with sugarcane bagasse ash, metakaolin, and millet husk ash as ternary cementitious material. *Environmental Science and Pollution Research*, 29(4), pp.5224-5239.
- [29] Bheel, N., Awoyera, P., Shar, I.A., Abbasi, S.A. and Khahro, S.H., 2021. Synergic effect of millet husk ash and wheat straw ash on the fresh and hardened properties of Metakaolin-based self-compacting geopolymer concrete. *Case Studies in Construction Materials*, 15, p.e00729.
- [30] Bheel, N., Memon, F.A. and Meghwar, S.L., 2021. Study of fresh and hardened properties of concrete using cement with modified blend of millet husk ash as secondary cementitious material. *Silicon*, 13(12), pp.4641-4652.
- [31] Bheel, N., Ali, M.O.A., Shafiq, N., Almujiabah, H.R., Awoyera, P., Benjeddou, O., Shittu, A. and Olalusi, O.B., 2023, March. Utilization of millet husk ash as a supplementary cementitious material in eco-friendly concrete: RSM modelling and optimization. In *Structures* (Vol. 49, pp. 826-841). Elsevier.
- [32] Bheel, N., Alwetaishi, M., Jae, I.A., Syamsir, A., Alraeeini, A.S., Waheeb, S.A., Alkhatabi, L. and Benjeddou, O., 2024. Enhancing performance and sustainability of GGBFS-based self-compacting geopolymer concrete blended with coal bottom ash and metakaolin by using RSM modelling. *Scientific Reports*, 14(1), p.19754.
- [33] Bheel, N., Chohan, I.M., Ghoto, A.A., Abbasi, S.A., Tag-eldin, E.M., Almujiabah, H.R., Ahmad, M., Benjeddou, O. and Gonzalez-Lezcano, R.A., 2024. Synergistic effect of recycling waste coconut shell ash, metakaolin, and calcined clay as supplementary cementitious material on hardened properties and embodied carbon of high strength concrete. *Case Studies in Construction Materials*, 20, p.e02980.
- [34] Keerio, M.A., Saand, A., Chaudhry, R., Bheel, N., ul Karim Bhatti, N. and Soohu, S., 2022. The effect of local metakaolin developed from natural material soorh on selected properties of concrete/mortar. *Silicon*, 14(4), pp.1807-1816.
- [35] Saand, A., Ali, K., Kumar, A., Bheel, N. and Keerio, M.A., 2021. Effect of metakaolin developed from natural material Soorh on fresh and hardened properties of self-compacting concrete. *Innovative Infrastructure Solutions*, 6(3), p.166.
- [36] Bheel, N., Kumar, S., Kirgiz, M.S., Ali, M., Almujiabah, H.R., Ahmad, M. and Gonzalez-Lezcano, R.A., 2024. Effect of wheat straw ash as cementitious

- material on the mechanical characteristics and embodied carbon of concrete reinforced with coir fiber. *Heliyon*, 10(2).
- [37] Katman, H.Y.B., Khai, W.J., Bheel, N., Kirgiz, M.S., Kumar, A., Khatib, J. and Benjeddou, O., 2022. Workability, strength, modulus of elasticity, and permeability feature of wheat straw ash-incorporated hydraulic cement concrete. *Buildings*, 12(9), p.1363.
- [38] Shar, I.A., Memon, F.A., Bheel, N., Benjeddou, O. and Alwetaishi, M., 2023. Effect of used engine oil on the mechanical properties and embodied carbon of concrete blended with wheat straw ash as cementitious material. *Environmental Science and Pollution Research*, 30(30), pp.75879-75893.
- [39] S. Nawel, L. Mounir, H. Hedi, Effect of temperature on pozzolanic reaction of Tunisian clays calcined in laboratory, *SN Appl. Sci.* 2 (2020).
- [40] M. Maier, N. Beuntner, K.C. Thienel, An Approach for the Evaluation of Local Raw Material Potential for Calcined Clay as SCM, Based on Geological and Mineralogical Data: Examples from German Clay Deposits, *RILEM Bookseries*. 25 (2020) 37–47.
- [41] K. Scrivener, F. Martirena, S. Bishnoi, S. Maity, Cement and Concrete Research Calcined clay limestone cements (LC 3), *Cem. Concr. Res.* 114 (2018) 49–56.
- [42] A. Tironi, M.A. Trezza, A.N. Scian, E.F. Irassar, Assessment of pozzolanic activity of different calcined clays, *Cem. Concr. Compos.* 37 (2013) 319–327.
- [43] R. Fernandez, F. Martirena, K.L. Scrivener, The origin of the pozzolanic activity of calcined clay minerals: A comparison between kaolinite, illite and montmorillonite, *Cem. Concr. Res.* 41 (2011) 113–122.
- [44] S.E. Schulze, J. Rickert, Suitability of natural calcined clays as supplementary cementitious material, *Cem. Concr. Compos.* 95 (2019) 92–97.