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Investigation of the Ability of Producing Eco-Friendly Roller Compacted Concrete Using Waste Material

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ABSTRACT

The major objective of the experimental lab investigation was to produce eco-friendly sustainable roller compacted concrete (RCC) by reducing cement content once using demolition waste material. The best method of disposing of waste demolition without needing for a sanitary landfill was by accumulating, crushing and then blending to a high fineness powder, followed by using it in materials such as clay bricks, marble tiles, and glass windows. Six RCC mixtures with partial cement weight replacements of 5%, and 10% were made in addition to the reference mixture. To investigate the strength (compressive, flexural and tensile splitting strength), porosity, water absorption, and density were all tested after the production of mixtures. The results of the study indicate that the RCC containing 10% of clay bricks powder enhances the strength of RCC up to 14.78%, 17.96%, and 12.87% for compressive, tensile, flexural, respectively, at 28-days of curing compared to the reference mixture, followed by the mixture containing 10% of marble tiles powder with percentage increase up to 7.12%, 14.44%, and 7.02%. While the glass windows with 5% can be adopted, the results close to reference mixture with slight improvement equal to 0.68%, 2.11%, and 3.22%, and slight reduction when using 10% replacement of cement weight, were obtained.

Keywords: roller compacted concrete, clay bricks powder, marble tiles powder, glass windows powder.

INTRODUCTION

Roller compacted concrete (RCC) pavement: type of concrete that is less expensive and more favorable to the environment as compared with traditional concrete, since the RCC mix has 12% cementitious materials as contrasted with 15% in conventional concrete (Abbas, 2022). A roller compacted concrete is made of cement, aggregates, and water; this mixture is produced using the same processes as asphalt paving as it is compacted by a heavy vibrating steel drums and rollers with rubber tires (ACI 327-R, 2015). RCC is usually placed in lifts of 150–200 mm with a 100 mm – minimum, and 250 mm – maximum (ACI PRC-309.5, 2022). Due to the thermal disintegration of calcium carbonate during the production of cement clinker and the combustion of fossil fuels utilized to heat the cement production process, about (1.25) tons of CO_2 emissions occur for every ton of cement (Bakhoum et al., 2023). Additionally, the consumption of energy in the cement industry contributes significantly to environmental problems. Production of cement is one of the energy-intensive industrial processes over all sectors (Babor et al., 2019). Green concrete described as "a form of eco-friendly concrete" that was produced utilizing waste materials from different industries as partial substitute of cement weight, and demands lesser energy for production, lowering the amount of cement in the mix resulted a reduction in pollutants. Also, the concrete became less expensive and more durable, and it emits less carbon dioxide (Al-Mansour et al, 2019, Sivakrishna et al, 2020, Suhendro, 2014). Several studies are continued on using waste-materials such as furnace slag, pulverized fly ash, and waste glass powder as a substitute for cement (Abbas et al., 2017). Waste material with a high-fineness mechanical property improves durability (Abbas et al., 2022). Therefore, waste materials are crushed, milled down to micro-sized particles, and blended before being used as partial- replacement of cement content to realize the creation of environmentally friendly concrete using RCC. The pozzolanic activity may be of great value, due to the possibility that an increase of strength can be achieved (Ahmad et al., 2022, Abbas, 2022, Shannag, 2000, Shannag and Yeginobali, 1995). Therefore, this might potentially be used as powders formed from clay bricks, marble tiles, and glass windows, which exhibit significant pozzolanic reactivity (Zhao et al, 2020, Hussain and Aljalawi, 2022, Naceri and Hamina, 2009). Moreover, it is necessary to take into consideration several features that might affect the pozzolanic reaction of the waste powder, in addition to the chemical composition of the powders, such as the grain size, the presence of additional additives, the particle shape, and other factors (Tagnit-Hamou, 1995).

The following three parts were the main advantages of the research:

- Lowering the expenses of disposal of waste materials, which are expected to rise because of increased levies on landfills.
- Saving thousands of raw resources that will protect the environment.
- Improving usable existing landfills and helping in the preservation of the landscape.

MATERIALS PROPERTIES AND MIXTURE DESIGN

The RCC mix consisted of the following:

- Ordinary Portland cement (type I): the chemical and physical characteristics of cement are illustrated in Table 1.
- Aggregate: crushed coarse aggregate had been utilized with a nominal maximum size of (19

Table 1. Ordinary Portland cement properties

Specification	Chemical composition / Oxide (%)								Vicat's setting time (min)		Strength (MPa)	
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	L.O.I	I.R.	Initial	Final	3- days	7-days
Results-OPC	60.2	20.2	4.10	2.95	2.16	2. 1	2.90	0.58	17.4	34.9	23.0	27.0
ASTMC150 (ASTM)	-	-	-	-	≤ 3.0	≤ 6.0	≤ 3.0	≤ 1.50	≥ 45.0	≤ 600	≥ 12.0	≥ 19.0

Table 2. Different properties of natural sand aggregate

Specification	SO_3 (%)	Specific gravity	Absorption (%)	Sieve size (mm)						
				10	4.75	2.36	1.18	0.6	0.3	0.15
Cumulative passing (%)	0.33	2.56	1.52	100	96	89	74	53	27	7
ASTMC33	-	-	-	100	95–100	80–100	50–85	25–60	5–30	0–10

Table 3. Different properties of coarse crushed aggregate of 4.75–19 mm

Specification	SO_3 (%)	Specific gravity	Absorption (%)	Sieve size (mm)			
				25	19.5	9.5	4.75
Passing (%)	0.06	2.62	0.42	100	97	48	7
ASTMC 33	-	-	-	100	90–100	20–55	0–10

Table 4. Characteristics of waste powder

Specification	Chemical composition (%)			Physical properties (%)	
	SiO_2% + Al_2O_3% + Fe_2O_3%	SO_3	L.O.I.	Retained wet sieved (45 μm)	Strength- activity index
Clay brick (B)	81.02	0.10	0.62	0	82.8
Marble tiles (M)	70.00	0.90	8.80	2	78.5
Glass windows (G)	75.8	0.34	3.80	30	76.2
ASTM C618 Class N	≥ 70	≤ 4%	≤ 10%	≤ 34%	≥ 75% at 28 days

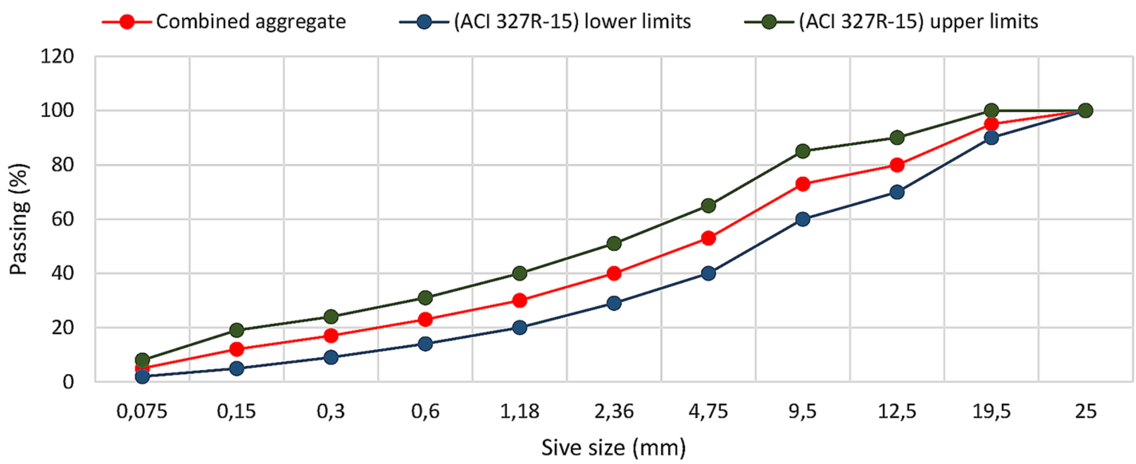

Figure 1. Combined aggregate gradation

Figure 2. Preparing process of demolition waste powder

mm), and for fine aggregate, natural sand had been employed (lower than 4.75 mm). The ASTM C33 (ASTM C33/C33M-16, 2016) grading standards were adopted to compare the fine and coarse aggregate grading. The characteristics of fine and coarse aggregate are shown in Tables 2 and 3, respectively.

For combined aggregate used in RCC, the ACI 327 suggests grading limitations, in this research, these limits were applied to determine the grading of combined aggregate as shown in Figure 1:

- Limestone filler (LF): fine material that passed through sieve number 200
- Finally, waste demolished materials: (clay bricks, marble tiles, and glass windows) were collected from different building sites for use in RCC samples as cement weight replacement by 5, and 10% after preparing the procedure showed in Figure 2, and conforming the requirements according to ASTM C618 (ASTM C618-17a, 2017), illustrated in Table 4.

MIXTURE PROPORTIONING

This research was conducted on six different RCC mixtures containing waste material and reference mixture (R). The materials used to produce the RCC mixes in this study are natural sand, crushed stone, cement, and various waste powder materials (clay bricks, marble tiles, and glass windows) with 5% (B5, M5, G5), and 10% (B10, M10, G10) replacement by weight of cement, respectively. Adopting the ACI 327 process design, the cement was chosen as a percentage by weight of all dry components, with percentage of 13% with gradation tests to determine the amount of coarse crushed stone, natural sand, and filler equal to 50, 44, and 6%, respectively. To reach the proper water content and density for RCC, the ASTM D1557 (ASTM D1557-12, 2012) standard was used. Depending on various water contents specified by ACI 327 and ACI 211 (ACI 211-3R, 2002 (09)), the optimum moisture content (OMC) relative to maximum dry density (max γ dry kg/m³) for each type of waste powder were calculated using the modified -proctor test (method C) conforming to ASTM D1557. A five point modified Proctor curve is developed using moisture contents ranging from 4.5% to 8.5% with 1% increases. For each Proctor point, 5.64 kg of combined aggregates 2.64 kg of fine aggregate plus 3 kg of coarse aggregate and filler of 0.36 kg are mixed with the calculated cement and water contents.

CASTING METHODOLOGY ADOPTING THE ASTM C1435 RCC MIXTURE

Adopting the ACI 327 recommendations to use the ASTM C1435 (ASTM C1435/C1435M-14, 2014) by using vibrating hammer technique in preparation of cylinder which can be tested in compressive and splitting strength without doubtful results, as recommended with many researchers interested in studying if there are significant differences between lab test method and field construction (Rahmani et al., 2020; Shafigh et al., 2020). The vibrating hammer (VH)

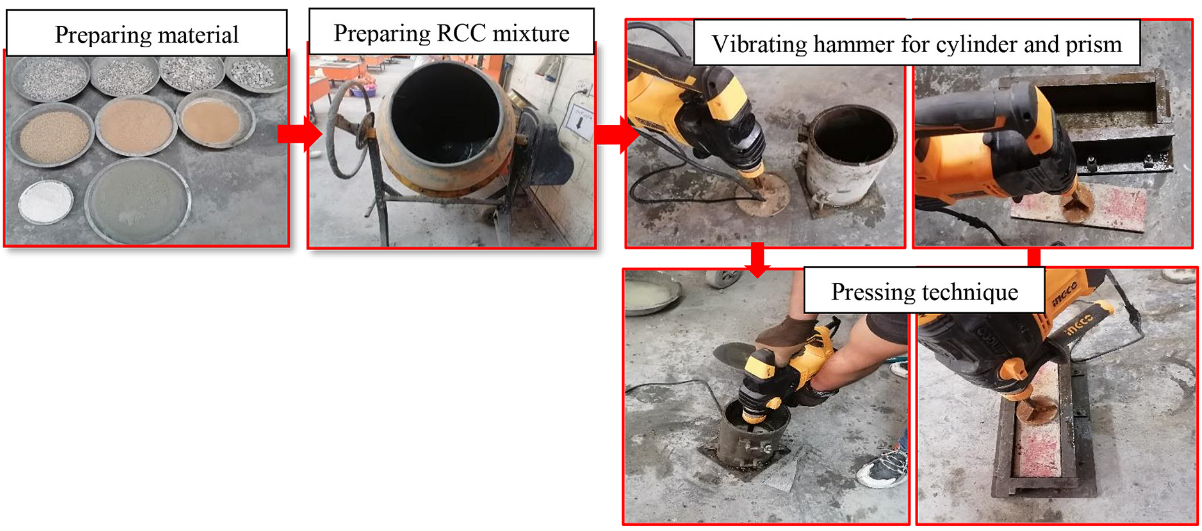

Figure 3. Compacting steps using vibrating hammer –ASTM C1435 for RCC mixture

Table 5. Specifications of the manufactured vibrating hammer for cylinder and beam molds

Criteria		Information	ASTM C1435	
Vibrating hammer	Vibrating compaction hammer mass (without tamping plate and shaft)	9 kg	8.5 to 13.5 kg	
	Power input	1500 W	Minimum power input of 900 W	
	Impacts/min	2200	2000 ± 200 impacts/min	
Steel plate attached to a steel shaft	Tamping cylinder plate diameter	149 mm	146 ± 3 mm	
	Tamping cylinder plate and shaft assembly mass	3 kg	3 ± 1 kg	
	Tamping beam plate dimensions	(98*398) mm	-	
	Tamping beam plate and shaft assembly mass	6.8 kg	-	

information are presented in Table 5, tack to consideration the manufacturing the rectangular plate adopting the same weight distribution and thickness of cylinder plate (LaHucik et al., 2017; Adamu et al., 2017; Madhkhan et al., 2012), and the procedure steps are presented in Figure 3.

EXPERIMENTAL WORK-LAB TESTS

The used RCC mix was molded in the following shapes:

- Cylinder size of (150×300 mm) for compressive strength test and splitting tensile strength

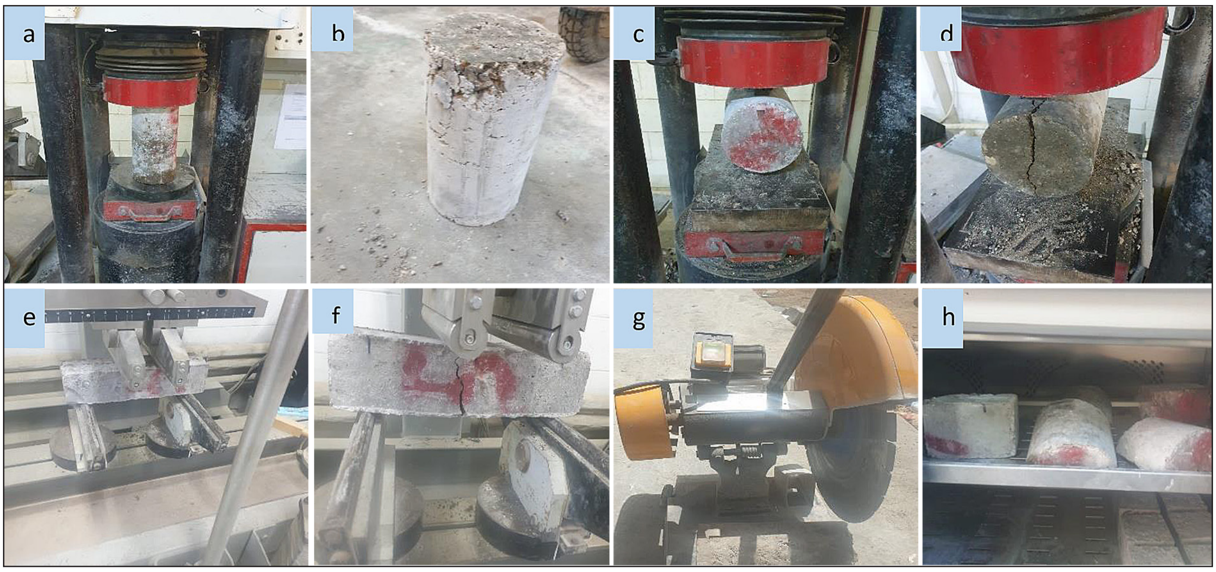

Figure 4. (a) Specimen in compressive-test machine (b) Specimen after failure due to compressive stress (c) Specimen in splitting test machine (d) Specimen after failed due to tensile stress (e) Specimen in flexural testing machine (f) Specimen after failure due to flexural stress (g) Cutting the specimens, and (h) Drying the specimens for 1 day

test. Cured by immersion in a water tank with a (23 ± 2 °C) temperature setting from the time of molding until the moment of test adopting the ASTM C192 (ASTM C192/C192M-16, 2016) and tested following to the ASTM C39 (ASTM C39/C39M-15a, 2015) and ASTM C496 (ASTM C496/C496M-11, 2011), respectively.
- Prism size of (100×100×400 mm) for flexural strength test, cured by immersion in a water tank with a 23± 2 °C temperature setting from the time of molding until the moment of test adopting the ASTM C192 and tested following to the ASTM C78 (ASTM C78/C78M-16, 2016).

The process was utilized to calculate the density, porosity, and absorption of RCC specimens illustrated in ASTM C642 (ASTM C642-13, 2013). After cutting a part from cylinder and prism specimens into individual parts, the test was conducted on parts of prisms and cylinders with a volume of greater than 300 cm³ for each piece. The specimens that had been curing at 28 days were used for the test. Figure 4 illustrates the experimental lab tests processes.

RESULTS AND DISCUSSION

Modified compaction (proctor) test results

Table 6 and Figure 5 present the results of Proctor compaction test in order to find the optimum moisture content relative to the maximum dry density for reference mix and other sustainable RCC mixtures. The maximum dry density for different mixes with an insignificant variance, since the low percentage replacement of cement

Table 6. Optimum moisture relative to maximum- dry densities for all RCC mixtures

Mix ID	OMC (%)	Max- γ dry (kg/m³)
R	6.3	2337
B5	6.35	2341
B10	6.4	2346
M5	6.25	2324
M10	6.22	2318
G5	6	2312
G10	5.8	2300

weight, and for the close particle size distribution were compatible with reasonable difference of OMC for sustainable RCC mixtures.

For other mixtures, compared to reference mixture, it was taken into consideration that the brick powder mixture showed higher OMC than reference mix for their high fineness and particle texture and shape (Abbas and Abd, 2021; Taha and Nounu, 2009; Liu et al., 2017). In turn, marble and glass powder mixture showed less OMC than reference mixture, also for their coarser particles size and texture shape (Du and Tan, 2014; Abbas and Abbood, 2021), and the decrease in OMC increased along with percentage replacement of cement weight from 5% to 10%.

Strength lab tests results for all different RCC specimens

The compressive, splitting tensile, and flexural strength properties were presented and discussed at 28 days and 90 days for reference mix (R), and for all other RCC mixes containing partial replacement of cement by weight 5% and 10%.

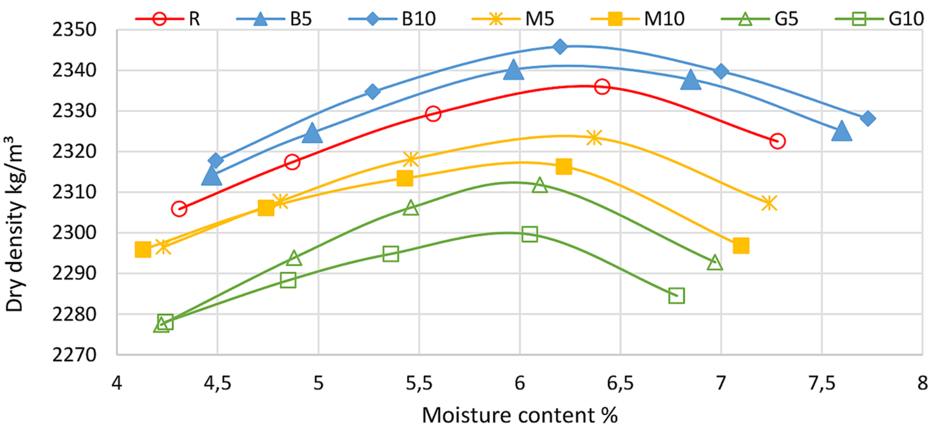

Figure 5. Moisture density curve for the different mixture

Compressive strength

Figure 6 displays the results of compressive strength tests of RCC samples after 28 days and 90 days of curing, it can be observed that RCC mixtures with various recycled powders (B5, B10, M5, M10, and G5) achieve compressive strengths higher than the minimum limit required in ACI 327 equal to (28 MPa); thus, these results approved the ability to produce a sustainable RCC using waste demolished powder with 10% safely and without risk of compressive strength deterioration. The RCC mixture containing the clay bricks powder with 5% and 10% with mix ID (B5 and B10) showed the highest compressive strength results equal to 31.92 MPa and 33.86 MPa, respectively at 28 days of curing, with a percentage of 8.2% and 14.7% respectively. The second improvement of compressive strength mixture for RCC containing marble tiles powder of mixture ID (M5 and M10) mix equal to 30.8 MPa and 31.6 MPa, respectively with percentage increase equal to 4.41% and 7.12%, respectively compared to reference RCC mix. Followed by the RCC mixture manufactured using 5% glass windows powder (G5) mix as a partial replacement - cement by weight which shows a slight increase in the compressive strength 29.7 MPa at 28 days of curing, as compared with the reference RCC mixture by 0.68%. In turn, the RCC mixture manufactured using 10% glass windows powder (G10) mix as a partial replacement of cement by weight shows an obvious decrease in the compressive strength 28.2 MPa at 28 days of curing, as compared with the reference RCC mixture by -4.41%, considering that the mixture is still within ACI code requirements. Chemically, the rise in compressive strength might have attributed to the pozzolanic activity of the waste highly fine powders used, which continued to consume

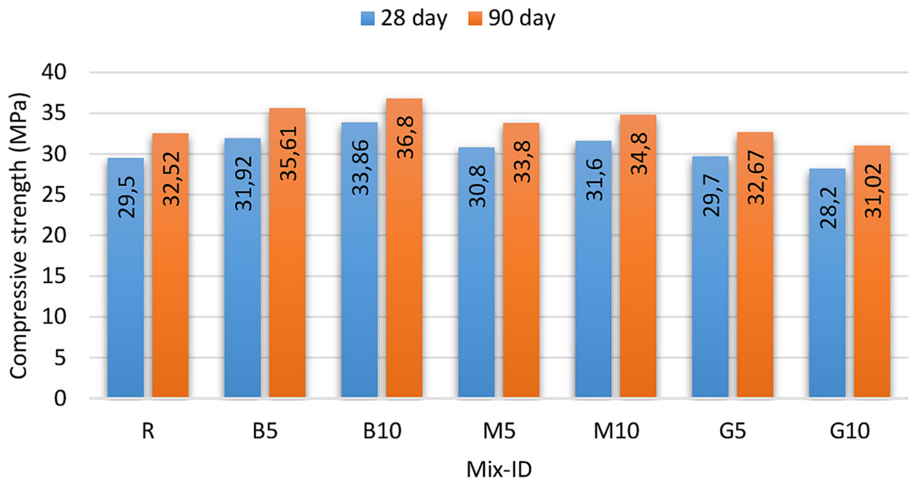

Figure 6. Compressive strength of various RCC mixtures at 28 days and 90 days

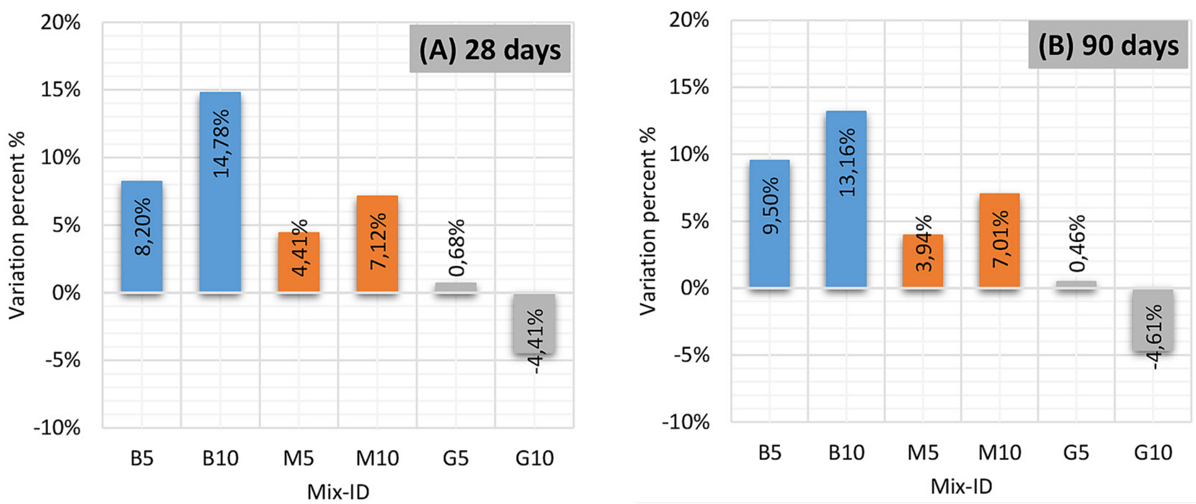

Figure 7. Variation percent for RCC mixtures containing different powder as compared with reference mix at (A) 28 days, and (B) 90 days – compressive strength

$Ca(OH)_2$ and produce (C-S-H: gel) and as a consequence, compressive strength will be increased as a result of this interaction. In addition to the particle filling ability effect (Norhasri, 2017), this phenomenon also explains the decrease of (G10) mix with crosser particle and shape compered to cement. The compressive strength of the various RCC mixtures with 5% partial replacement of different types of recycled powder by cement weight (B5, M5 and G5) at 90 days of cure continued to grow 35.61 MPa, 33.8 MPa, and 32.67 MPa respectively, and the same state for the RCC mixtures with 10% partial replacement of different types of recycled powder by cement weight (B10, M10, and G10) which records 36.8 MPa, 34.8 MPa, and 31.02 MPa, respectively. The cause may be attributed to the increased maturity of concrete with age in addition to the contribution of combined effects of cement hydration and pozzolanic activity (Dunstan, 2011, Shaikh and Supit, 2015, Shi, 2001). Figure 7 shows the variation percent for RCC mixtures containing different powders as compared with reference mix.

Splitting-tensile strength results

Figure 8 show the results of splitting tensile strength tests of RCC samples after 28 days and 90 days of curing. It can be observed that RCC mixtures with various recycled powders (B5, B10, M5, M10, and G5) had splitting tensile strength that was increased as compared to the reference RCC mixture by 15.85, 17.96, 9.86, 14.44, and 2.22%, respectively for 28 days, and 16.04, 20.14, 9.9, 14.68, and 1.71%, respectively, at 90 days of curing. This increase in splitting tensile strength could be attributed to the powders which represent supplementary materials like silica and free lime and giving stiffer structure after reaction (Sukmana et al., 2019, Modarres et al., 2018, Supit, and Shaikh, 2015). On the other hand, the RCC mixtures with 10% glass powder (G10) had splitting tensile strength that was decreased as compared to

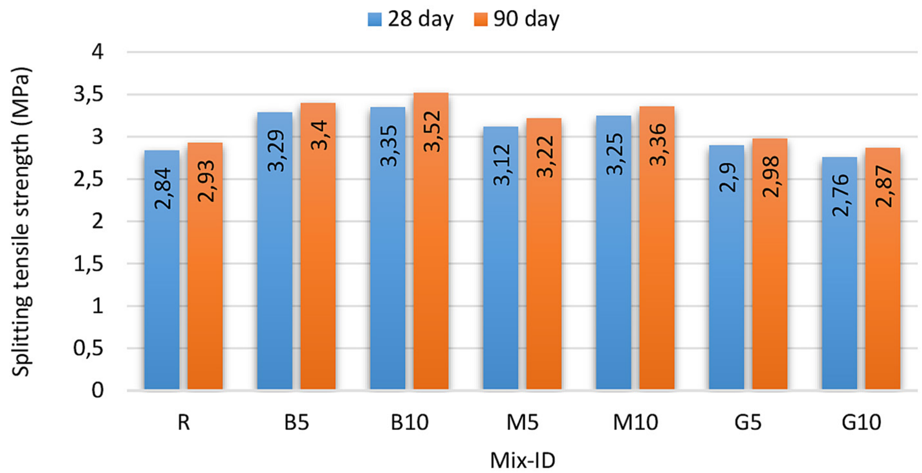

Figure 8. Splitting tensile strength of different RCC mixtures at 28 days and 90 days

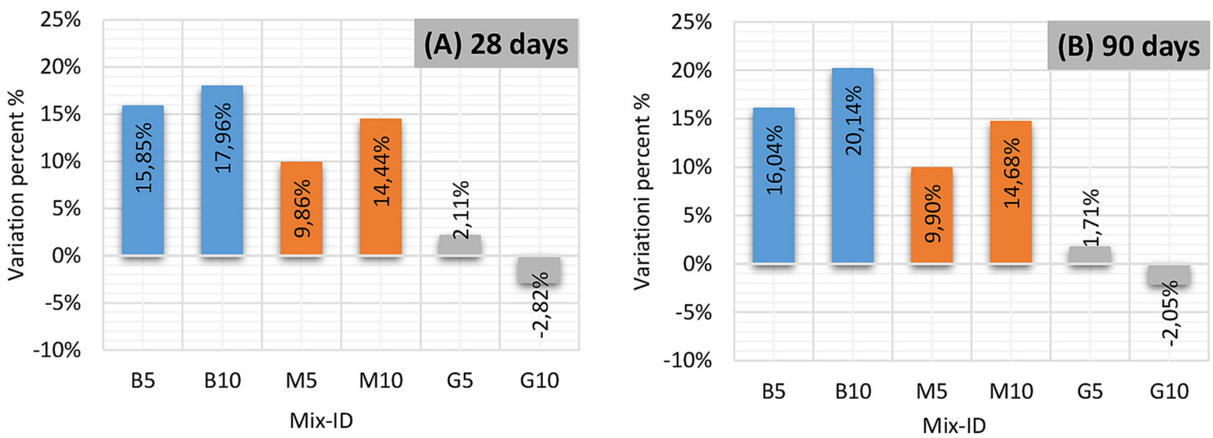

Figure 9. Variation percent for RCC mixtures containing different powder as compared with reference Mix at (a) 28 days, and (b) 90 days – splitting tensile strength

the reference RCC mixture by -2.82%, and -2.05% at 28 days and 90 days, respectively, due to the particle filling effect. Figure 9 shows the variation percent for RCC mixtures containing different powders, as compared with the reference mixture.

Flexural strength results

Figure 10 shows the results of flexural strength tests of RCC samples after 28 and 90 days. It can be observed that all RCC mixtures with various recycled powders (B5, B10, M5, M10, and G5) had flexural strengths that were increased as compared to the reference RCC mixture by 8.48, 12.87, 4.68, 7.02, and 3.22%, respectively, for 28 days. The flexural strength of various RCC mixtures kept increasing after 90 days of curing and recorded the increasing percentage 15.66, 23.63, 9.34, 13.46, and 3.85%, respectively, when compared with the reference mix at 90 day of curing. The presence of pozzolanic activity of these powders may be responsible for the increase in flexural strength, which react with the Ca(OH)2 produced from cement hydration, this reaction produces more (C-S-H: gel), which will fill the pores in the RCC mixture and dense the cement structure, and improve the mechanical properties of the hardened RCC, moreover to the effect of the filling pores of powders (Arroudj et al., 2017, Ramezanianpour et al., 2010). On other hand, the RCC mixtures with 10% glass powder (G10) had flexural strength that were a decreased as compared to the reference RCC mixture by -1.75%, and -6.04% at 28 days and 90 days, respectively, due to the particle filling effects. Figure 11 shows the variation percent for RCC mixtures containing different powder as compared with reference Mix.

Density, absorption, and porosity results

Figure 12, Figure 13, and Figure 14 illustrate the results of density, absorption, and porosity, respectively, for RCC samples after 28 days of

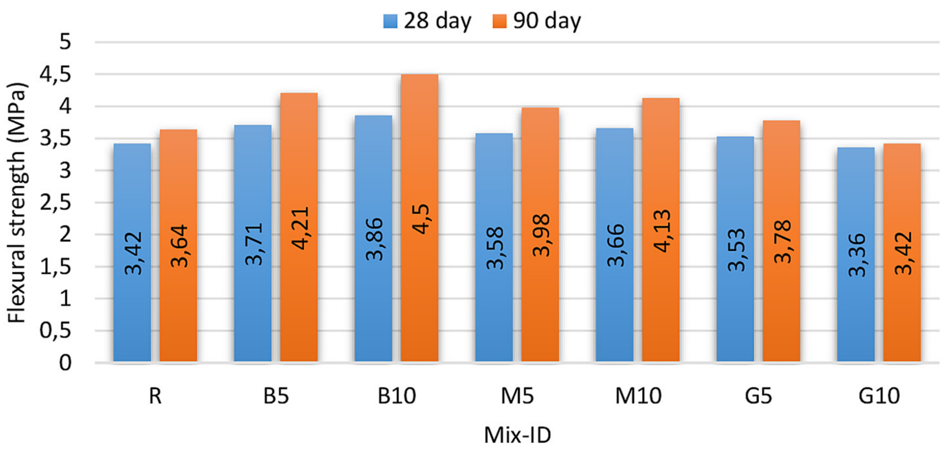

Figure 10. Flexural strength of different RCC mixtures at 28 days and 90 days

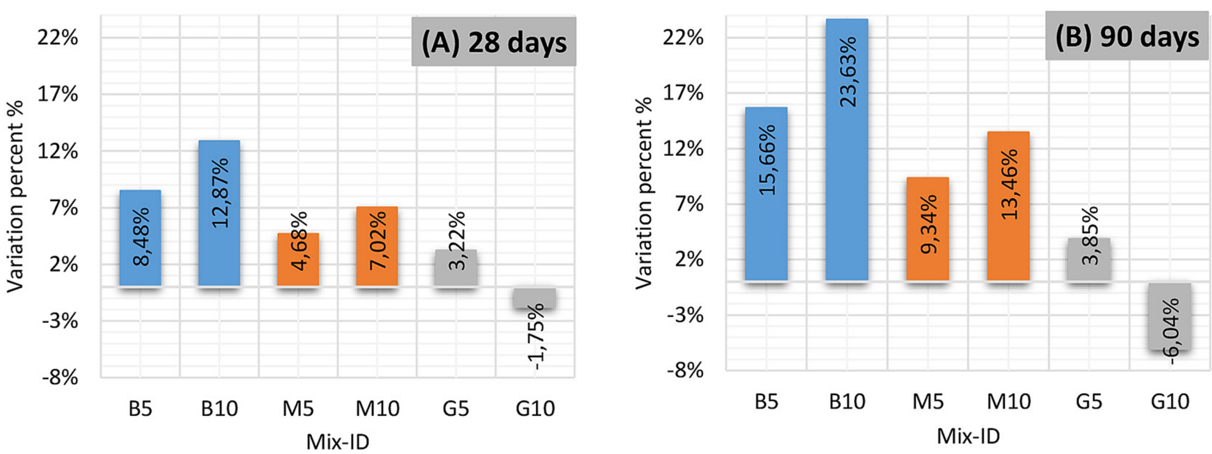

Figure 11. Flexural strength percent increase for RCC mixtures containing different powder as compared with reference Mix at (a) 28 days, and (b) 90 days

curing. It can be observed that when clay brick powder were used in RCC mixtures as a partial replacement of cement by weight (B5, B10), the density had been improved, and the water absorption and porosity had been decreased as compared with the reference mixture.

Physically, the reason for this could be that the effect of the filling pores with high fin powder ne and reduces gaps. Chemically, due to the pozzolanic activity of the clay brick powder results in the formation of additional hydration products (C-S-H: gel), in consequence leading to pore refinement and porosity reduction, forming denser pore structure, as a result this will rise the density and decrease the voids in the RCC, resulting in lower porosity; and the water absorption will decrease (Elavenil and Vijaya, 2013). Also, when the marble tiles powder were used in the RCC mixture as a partial replacement of cement by weight (M5, M10), the resulting density was slightly decreased with the density of the reference mixture. This

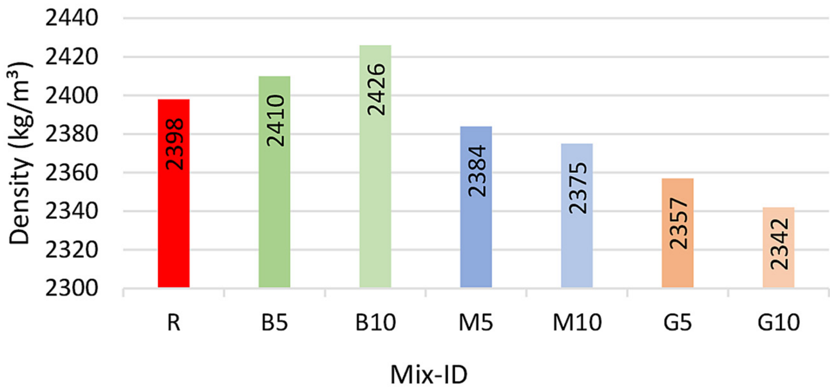

Figure 12. Density for different RCC mixtures at 28 days

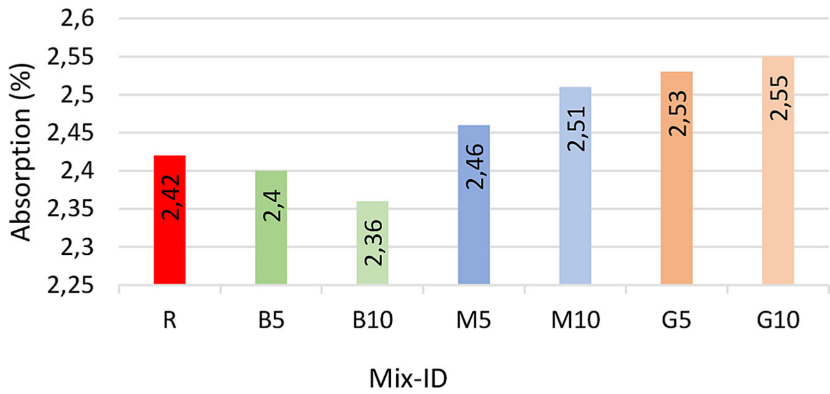

Figure 13. Absorption for different RCC mixtures at 28 days

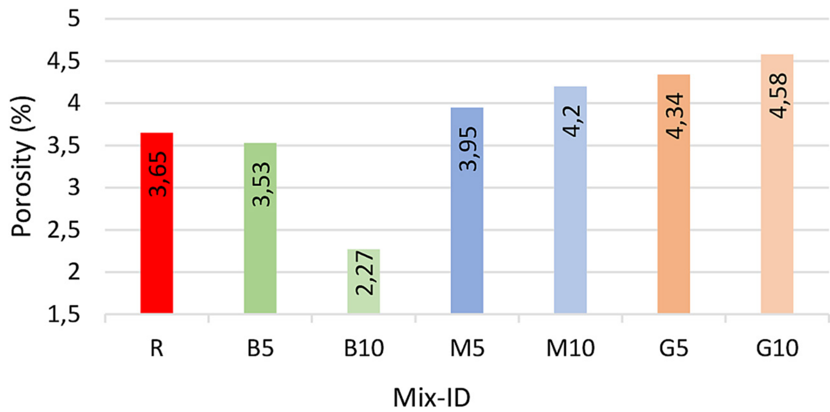

Figure 14. Porosity for different RCC mixtures at 28 days

could be because of lower density of marble tiles powder than cement. On the other hand, the absorption and porosity of the marble tiles powder mixture decreased slightly when compared with the reference mixture, due to the pozzolanic activity of marble tiles powder, which is at a slow rate at an early age. Moreover, when glass windows powder was used in RCC mixture as a partial- replacement of cement by weight (G5, G10), the density significantly decreased, whereas the absorption and porosity increased, as compared with reference mixture. The decrement of density maybe because glass window powder has a lower density than cement, also because of the higher percentage of voids in the RCC made with glass windows powder. Also, it was concluded that the porosity negatively affects the RCC, which proves the significance of RCC compaction for attaining better mechanical properties (Fardin and Santos, 2020).

CONCLUSIONS

Based on the experimental lab results found the following conclusions can be formulated:

1. The increase in strength of the RCC containing 5% of waste fine-powder materials (clay bricks, marble tiles, or glass windows) as a partial substitute of cement weight equal to 8.2, 4.41, 0.68%, 15.85, 9.86, 2.11%, and 8.48, 4.68, 3.22% for (compressive-splitting tensile – flexural strengths) respectively at 28 days in comparison compered to reference mixture and up to 9.5, 3.94, 0.46%, 16.04, 9.9, 1.71%, and 15.66, 9.34, 3.35% for (compressive-splitting tensile – flexural strengths) respectively, at 90 days.
2. The 10% replacement of (clay bricks and marble tiles) powders shows greater development in strength than the reference mixture (Abbas et al., 2023).
3. The ability to produce sustainable RCC employing 5% sustainable demolished waste material (clay bricks, glass windows, or marble tiles) led to an improvement in mechanical strength.
4. The ability to produce of sustainable RCC containing 10% replacement of cement weight reduced cement use and allows for the disposal of larger quantities of materials from demolished buildings (clay bricks and marble tiles), safely taking care of hazardous materials when using glass window waste.

REFERENCES

1. Abbas, Z.K., 2022. Roller compacted concrete: Literature review. Journal of Engineering, 28(6), 65-83.lab, American concrete. Institute, 327R.
2. ACI 327-R, 2015. Guide to roller-compacted. Concrete, Pavements, American concrete. Institute, 327R.
3. ACI PRC-309.5, 2022. Compaction of roller-compacted concrete—report, American concrete. Institute, 327R.
4. Bakhoum, E.S., Amir, A., Osama, F. and Adel, M., 2023. Prediction model for the compressive strength of green concrete using cement kiln dust and fly ash. Scientific Reports, 13(1), 1864.
5. Babor, D., Plian, D. and Judele, L., 2009. Environmental impact of concrete. Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 55(4), 27.
6. Al-Mansour, A., Chow, C.L., Feo, L., Penna, R. and Lau, D., 2019. Green concrete: By-products utilization and advanced approaches. Sustainability, 11(19), 5145.
7. Sivakrishna, A., Adesina, A., Awoyera, P.O. and Kumar, K.R., 2020. Green concrete: A review of recent developments. Materials Today: Proceedings, 27, 54-58.
8. Suhendro, B., 2014. Toward green concrete for better sustainable environment. Procedia Engineering, 95, 305-320.
9. Abbas, Z.K., Abbood, A.A. and Awad, H.K., 2017. Some properties of mortar and concrete using brick, glass and tile waste as partial replacement of cement. Int J Sci Res, 6(5), 1210-5.
10. Abbas, Z.K., Abbood, A.A. and Mahmood, R.S., 2022. Producing low-cost self-consolidation concrete using sustainable material. Open Engineering, 12(1), 850-858.
11. Ahmad, S., Al-Amoudi, O.S.B., Khan, S.M. and Maslehuddin, M., 2022. Effect of silica fume inclusion on the strength, shrinkage and durability characteristics of natural pozzolan-based cement concrete. Case Studies in Construction Materials, 17, e01255.
12. Abbas, Z.K., 2022. Properties of Roller-Compacted Concrete Pavement Containing Different Waste Material Fillers. Journal of Engineering, 28(9), 86-106.
13. Shannag, M.J., 2000. High strength concrete containing natural pozzolan and silica fume. Cement and concrete composites, 22(6), 399-406.
14. Shannag, M.J. and Yeginobali, A., 1995. Properties of pastes, mortars and concretes containing natural pozzolan. Cement and Concrete Research, 25(3), 647-657.
15. Zhao, Y., Gao, J., Liu, C., Chen, X. and Xu, Z., 2020. The particle-size effect of waste clay brick powder

on its pozzolanic activity and properties of blended cement. Journal of cleaner production, 242, 118521.

16. Hussain, Z.A. and Aljalawi, N.M.F., 2022. Some properties of Reactive Powder Concrete Contain Recycled Glass Powder. Journal of Engineering, 28(10).
17. Naceri, A. and Hamina, M.C., 2009. Use of waste brick as a partial replacement of cement in mortar. Waste management, 29(8), 2378-2384.
18. Tagnit-Hamou, A., 1995. Microstructure et physico-chimie des ciments et des betons. Université de Sherbrooke, Québec.
19. ASTM C33/C33M-16, 2016. Standard Specification for Concrete Aggregates. West Conshohocken PA, USA: ASTM International.
20. ASTM C618-17a, 2017. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM International.
21. ASTM C150/C150M-18, 2018. Standard Specification for Portland Cement. West Conshohocken PA, USA: ASTM International.
22. ASTM D1557-12, 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 KN-m/m3). West Conshohocken PA, USA: ASTM International.
23. ACI 211-3R, 2002 (09). Guide for Selecting Proportions for No-Slump Concrete. Farmington Hills MI USA, USA: American Concrete Institute.
24. ASTM C1435/C1435M-14, 2014. Standard practice for molding roller-compacted concrete in cylinder molds using a vibrating hammer. Annual Book of ASTM standards. Philadelphia, PA: American Society for Testing and Materials.
25. Rahmani, E., Kazem, M., Sharbatdar, MBeygi, H.A., 2020. A comprehensive investigation into the effect of water to cement ratios and cement contents on the physical and mechanical properties of Roller Compacted Concrete Pavement (RCCP). Construction and Building Materials 253 (2020) 119177.
26. Shafigh, P., Hashemi, M., Nam, B.H. and Koting, S., 2020. Optimum moisture content in roller-compacted concrete pavement. International Journal of Pavement Engineering, 21(14), 1769-1779.
27. LaHucik, J., Dahal, S., Roesler, J. and Amirkhanian, A.N., 2017. Mechanical properties of roller-compacted concrete with macro-fibers. Construction and building materials, 135, 440-446.
28. Adamu, M., Mohammed, B.S. and Shafiq, N., 2017, May. Effect of mineral filler type on strength of roller compacted rubbercrete for pavement applications. In IOP conference series: materials science and engineering (Vol. 201, No. 1, 012011). IOP Publishing.
29. Madhkhan, M., Azizkhani, R., Torki Harchegani, M.E., 2012. Effects of pozzolans together with steel and polypropylene fibers on mechanical properties of RCC pavements. Construction and Building Materials, 26 102–112.
30. ASTM C192/C192M-16, 2016. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. West Conshohocken PA, USA: ASTM International.
31. ASTM C39/C39M-15a, 2015. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. West Conshohocken PA, USA: ASTM International.
32. ASTM C496/C496M-11, 2011. Standard test method for splitting tensile strength of cylindrical concrete specimens. United States: ASTM International.
33. ASTM C78/C78M-16, 2016. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). West Conshohocken PA, USA: ASTM International.
34. ASTM C642-13, 2013. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. West Conshohocken PA, USA: ASTM International.
35. Liu, S., Dai, R., Cao, K. and Gao, Z., 2017. The role of sintered clay brick powder during the hydration process of cement pastes. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 41, 159-165.
36. Taha, B. and Nounu, G., 2009. Utilizing waste recycled glass as sand/cement replacement in concrete. Journal of materials in civil engineering, 21(12), 709-721.
37. Abbas, Z.K. and Abd, S.K., 2021. Study of using of recycled brick waste (RBW) to produce environmental friendly concrete: A review. Journal of Engineering, 27(11), 1-14.
38. Abbas, Z.K. and Abbood, A.A., 2021, February. The influence of incorporating recycled brick on concrete properties. In IOP Conference Series: Materials Science and Engineering (Vol. 1067, No. 1, 012010). IOP Publishing.
39. Du, H. and Tan, K.H., 2014. Waste glass powder as cement replacement in concrete. Journal of Advanced Concrete Technology, 12(11), 468-477.
40. Norhasri, M.M., Hamidah, M.S. and Fadzil, A.M., 2017. Applications of using nano material in concrete: A review. Construction and Building Materials, 133, 91-97.
41. Dunstan, E.R., 2011, May. How does pozzolanic reaction make concrete green. In 2011 World of Coal Ash (WOCA) Conference (1-14). Ash Library, Denver, CO, USA.
42. Shaikh, F.U. and Supit, S.W., 2015. Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA). Construction and building materials, 82, 192-205.

43. Shi, C., 2001. An overview on the activation of reactivity of natural pozzolans. Canadian journal of civil engineering, 28(5), 778-786.
44. Supit, S.W.M. and Shaikh, F.U.A., 2015. Durability properties of high volume fly ash concrete containing nano-silica. Materials and structures, 48, 2431-2445.
45. Modarres, A., Hesami, S., Soltaninejad, M. and Madani, H., 2018. Application of coal waste in sustainable roller compacted concrete pavement-environmental and technical assessment. International Journal of Pavement Engineering, 19(8), 748-761.
46. Sukmana, N.C., Melati, M.S., Setyawan, M.I., Prayoggi, E. and Anggarini, U., 2019, April. Optimization of cellular lightweight concrete using silica sand of sandblasting waste based on factorial experimental design. In IOP Conference Series: Materials Science and Engineering (Vol. 509, No. 1, 012096). IOP Publishing.
47. Ramezanianpour, A.A., Mirvalad, S.S., Aramun, E. and Peidayesh, M., 2010, June. Effect of four Iranian natural pozzolans on concrete durability against chloride penetration and sulfate attack. In Proceedings of the 2nd international conference on sustainable construction materials and technology (28-30).
48. Arroudj, K., Lanez, M. and Oudjit, M.N., 2017. Characterization of cement mortar based on fine quartz. International Journal of Structural and Construction Engineering, 9(9), 1278-1281.
49. Elavenil, D.S. and Vijaya, B., 2013. Manufactured sand, a solution and an alternative to river sand in concrete manufacturing. International Journal of Civil Engineering Research and Development (IJCERD), 3(1).
50. Fardin, H.E. and Santos, A.G.D., 2020. Roller compacted concrete with recycled concrete aggregate for paving bases. Sustainability, 12(8), 3154.
51. Abbas, Z.K., Al-Baghdadi, H.A., Mahmood, R.S. and Abd, E.S., 2023. Reducing the Reactive Powder Concrete Weight by Using Building Waste as Replacement of Cement. Journal of Ecological Engineering, 24(8), 25-32.