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Reducing the Reactive Powder Concrete Weight by Using Building Waste as Replacement of Cement

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ABSTRACT

The ability of reducing the high weight of reactive powder concrete (RPC) by decreasing the cement content using waste demolished building material to produce the eco-friendly sustainable RPC was the main goal of the experimental lab investigation. The collecting, crushing and grinding to high fineness powder waste of clay brick, window glass and terrazzo tile constituted the best way to dispose without the need for a waste sanitary landfill. Nine RPC mixtures with 5, 10 and 15% partial replacement of cement weight in addition to control mix were prepared to investigate the strength. The slight enhancement strength of the RPC containing 5% of very fine powder clay brick or window glass or terrazzo tile as cement weight replacement cement up to (4.9, 4.2, 4.5)% – brick, (2, 1.8, 1.6)% – glass and (1.5, 0.5, 0.8)% – tile for (compressive – flexural – tensile), respectively, at 28 days compared to the control mix. The percentage of 10% still yielded acceptable strength results, while 15% presented the starting of reduction of (compressive – flexural – tensile) strength.

Keywords: reactive powder concrete, sustainable–eco-friendly concrete, clay brick, window glass, terrazzo tile.

INTRODUCTION

The reactive powder concrete (RPC) is a developed concrete considered as a composite materials with a high strength and good durability [Liu et al, 2019]. It consists of cement, silica fume and very fine sand where the microstructure is improved of all particles in the mix to produce maximum density [Khitab et al, 2022]. The presence of the short length fibers significantly recovers the quasi-brittle characteristics and tensile damaging capability of the concrete [Singh, 2017; Mishra et al, 2017].

Producing cement is responsible for approximately 8% of global CO_2 emissions, so the ability of reducing cement content in concrete led to reduced pollution and produced a green concrete which defined as a form of eco-friendly concrete that is manufactured using waste or residual materials from different industries, and requires less amount of energy for production. Compared to traditional concrete, it produces less carbon dioxide, and is considered cheap and more durable [Suhendro, 2014; Al-Mansour, 2019; Sivakrishna, 2020]. The transformation of the building demolition waste to fine powder can be done by serial steps: collecting, separating, and crushing, finally grinding to powder in order to use as partial replacement of cement content. The reclaimed natural pozzolan can be used in concrete production where cementitious or pozzolanic action, or both, is desired [Al-Anbori and Al-Obaidi, 2016; Qasim, 2021]. The pozzolanic action can be beneficial, since the development of strength can be gained, and with high fineness rich cement paste micro-structure can be significant [Shannag and Yeginobali, 1995; Shannag, 2000; Abbas, 2022; Ahmad, 2022]. It is necessary to consider the chemical and physical requirements presented in ASTM C 618 for class N [ASTM C618, 2017], and its ability to improve the fresh and mechanical properties especially at late ages, which increase along with particle size fineness that improve its effectiveness chemical reaction with cements silicates hydration ($Ca(OH)_2$) producing a good gel quality [Abdullah et al, 2022; Abbas, 2021]. The main goal of the investigation focused on two parts: disposing of the demolition waste by cycling and using in construction projects and reducing the RPC cost by decreasing the high content of cement, thus producing sustainable RPC with less environment pollution from cement manufacture and waste sanitary landfill.

MATERIALS AND MIX DESIGN

The mixture composition of the RPC were:

- Ordinary Portland cement (OPC-grade R42.5), conforming to IQS No.5 [IQS No. 5, 2019] as presented in Table 1.
- High finesse natural sand (zone 4-according to Iraqi classification) conforming the IQS No.45 [No.45, 1984] presented in Table 2.
- Fume silica conforming the ASTM C 1240 [ASTM C1240, 2015] presented in Table 3.
- Straight steel fiber with aspect ratio = 65 presented in Table 4.
- Hyperplast PC200 (high performance superplasticizing admixture) with guidance dosage equal to 0.50–2.50 liter/100 kg of cementitious materials in the mix conforming to ASTM C 494 [ASTM C494/C 494M-08a].
- Waste building materials (clay brick, window glass and terrazzo tile) which were used as cement weight replacement by (5, 10 and 15)% after the preparation process presented in Figure 1, and conforming requirements according to ASTM C618 [ASTM C618, 2018] presented in Table 5.
- Preparing recycled west demolished powder (Figure 1).
- The adoption mix design listed in Table 6 after many trials according to the works by

Table 1. Cement (OPC) properties

Parameter	Chemical composition/oxide (%)								Blaine surface (m^2/ kg)	Autoclave soundness (%)	Vicat's setting time (min)		Grade (MPa)	
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	L.O.I	I.R.			Initial	Final	2 days	28 days
Results OPC	63.02	19.97	6.05	3.18	2.19	1.89	2.69	0.4	53.27	17.14	10.65	9.66	21.5	43.8
IQS No.5	-	-	-	-	≤ 2.8	≤ 5.0	≤ 4.0	≤ 1.50	≥ 280	≤ 0.8	≥ 45	≤ 600	≥ 20	≥ 42.5

Table 2. Natural sand (NS) properties

Parameter	SO_3 (%)	Specific gravity	Absorption (%)	Finer 75 µm (%)	Sieve size (mm)						
					10	4.75	2.36	1.18	0.6	0.3	0.15
Cumulative passing (%)	0.2	2.59	0.75	2.1	100	98	97	92	85	30	5
IQS No. 45 (%)	≤ 0.5	-	-	≤ 5	100	95–100	95–100	90–100	80–100	15–50	0–15

Table 3. Fume silica (FS) properties

Parameter	Chemical composition (%)			Physical properties		
	SiO_2	Moisture content	L.O.I	Retained on 45-µm (%)	Pozzolanic strength activity index (%)	Specific surface (m^2/g)
Results FS	93.5	0.56	1.2	6.5	110.5	≥15
Specification- ASTM C 1240	≥ 85.0	≤ 3.0	≤ 6.0	≤ 10	≥105 at 7 days	≥15

Table 4. Steel fibers properties according to manufacture

	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Density (kg/m^3)
	13	0.2	2600	7800

Khreef and Abbas [2021] as well as Al-Hassani et al. [2015].

The adoption mix design listed in Table 6 after many trials according to the works by Khreef and Abbas [2021] as well as Al-Hassani et al. [2015].

PREPARATION OF SPECIMENS AND EXPERIMENTAL LAB TESTS

The mixing of material was as recommended by Khreef and Abb [2021] as well as Al-Hassani et al. [2015] taking into consideration the waste material combined with cement before starting of mixing.

The RPC mixture molded in three specimen shapes:

- Cubic size of 100 mm for compressive – strength test done in 2-layers adopting the BS 1881: part 108 [BS 1881: part 108, 1983] and tested according to BS EN 12390-3 [BS EN 12390-3, 2009].
- Cylinder size of 150×300 mm for splitting–strength test done in 3-layers adopting ASTM C192 [ASTM C192, 2011] and tested according to ASTM C496/C496M [ASTM C496/C496M, 2011].
- Prism size of 100×100×400 mm for flexural tests – strength test done in 2-layers adopting ASTM C192-11 and tested according to ASTM C78 [ASTM C78/C78M, 2018].

Table 5. Building waste powder properties

Parameter	Chemical composition (%)					Physical properties		
	SiO_2	Al_2O_3	Fe_2O_3	SO_3	L.O.I.	Retained wet sieved No. 325 (%)	Pozzolanic strength activity (%)	Specific gravity
Brick (B)	72.8	18.5	3.2	0.0	2.1	0	85.8	2.75
Glass (G)	62.5	8.5	1.2	0.0	5.8	15.5	80.6	2.68
Tile (T)	60.8	14.5	2.2	1.1	4.8	10.5	76.1	2.62
Specification ASTM 618 Class N	SiO_2+ Al_2O_3+ Fe_2O_3≥ 70			≤ 4%	≤ 10%	≤ 34%	≥ 75% at 7days	-

Table 6. Mixture contents (kg/m^3)

Content (kg/m^3)	Con.	B5	B10	B15	G5	G10	G15	T5	T10	T15
OPC	950	902.5	855	807.5	950	902.5	855	950	902.5	855
B	-	47.5	95	142.5	-	-	-	-	-	-
G	-	-	-	-	47.5	95	142.5	-	-	-
T	-	-	-	-	-	-	-	47.5	95	142.5
Contestant content	NS=1045; W=180; SP=20 (liter /m^3)-(≈2.1 liter/ 100kg cement); FS=225; SF=155 (≈2% of concrete)									

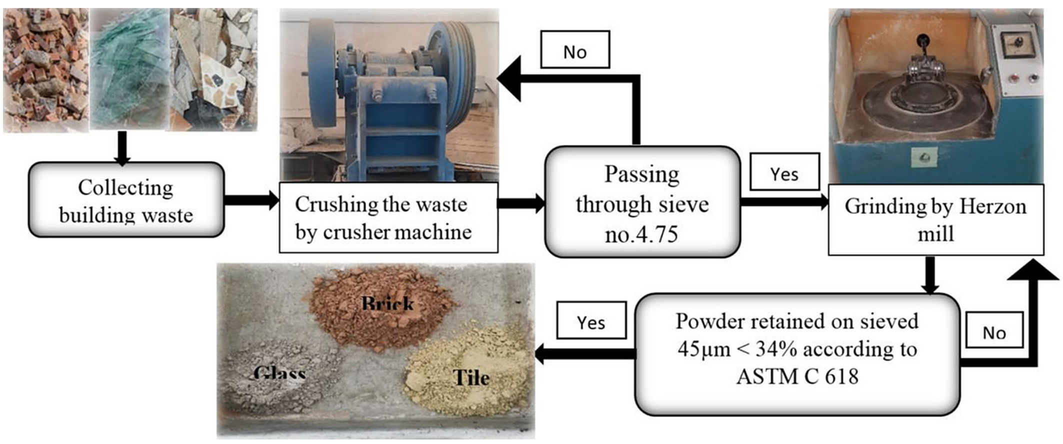


Figure 1. Preparing recycled west demolished powder

The process of the curing cycle was based on experience [Al-Hubboubi and Abbas, 2018; Khreef and Abbas, 2021], the local electricity conditions, and many trials of the curing cycle. Comparison between normal curing and cycle process was carried out till the adoption of curing cycle recommendation with percentage increase in compressive strength of more than 15% compared to standard curing (under water in lab). All details of the procedure described above and curing cycle are shown in Figure 2.

EXPERIMENTAL LAB TEST RESULTS AND DISCUSSION

The lab test results for compressive strength at 7, 28 and 90 days for control mixture and all other RPC using very fine powder waste materials (clay brick, window glass, terrazzo tile) as partial cement weight replacement by (5, 10 and 15)% are as shown in Figure 3. The percentage increase or decrease for the mixture containing demolition waste compared to control mix at 28-days is presented in Figure 4. The use of brick powder for 5% and 10% achieved an improvement in mechanical strength and the use of 15% yielded a slight decrease (1.1%), so the use of BP is very encouraging for its very fine cementitious filling material micro-structure of concrete and pozzolanic chemical reaction between silicates hydration of cement [$Ca(OH)_2$] and active silica of BP to form essential densification filling gel [Kasaniya et al, 2021; Abbas and Abd, 2021; Al-Anbori and Al-Obaidi, 2016; Abbas, 2022]. The window glass powder behavior was close to BP,

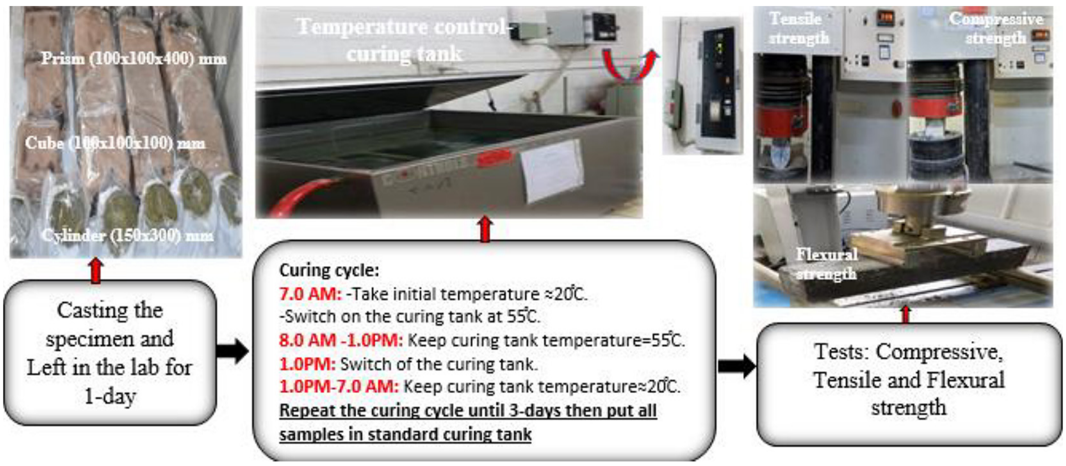
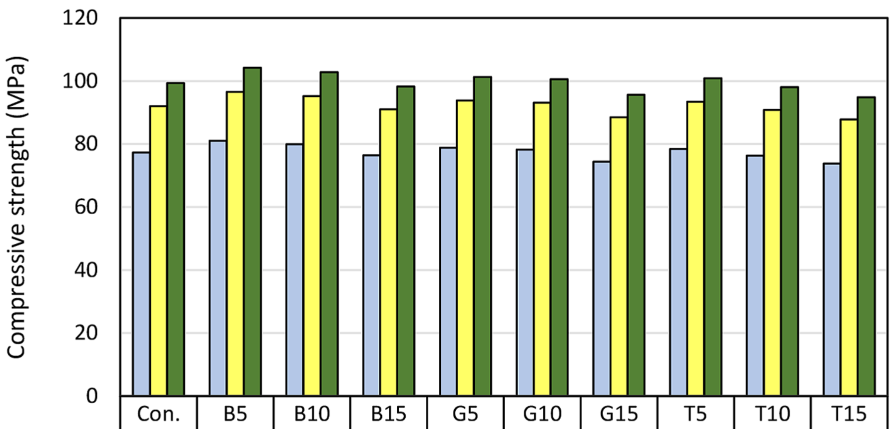
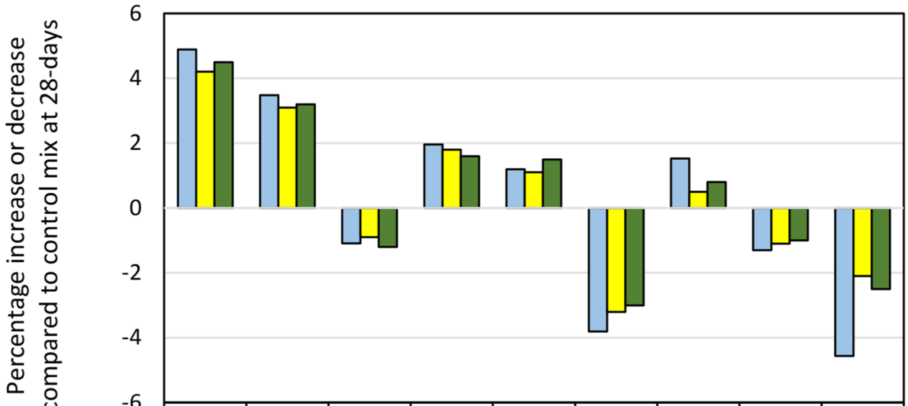


Figure 2. Casting, curing cycle and testing specimens



	Con.	B5	B10	B15	G5	G10	G15	T5	T10	T15
7-days	77,3	81,1	80,0	76,4	78,8	78,2	74,3	78,5	76,3	73,8
28-days	92	96,5	95,2	91	93,8	93,1	88,5	93,4	90,8	87,8
90-days	99,4	104,2	102,8	98,3	101,3	100,5	95,6	100,9	98,1	94,8

Figure 3. Compressive results for all mixes at different ages

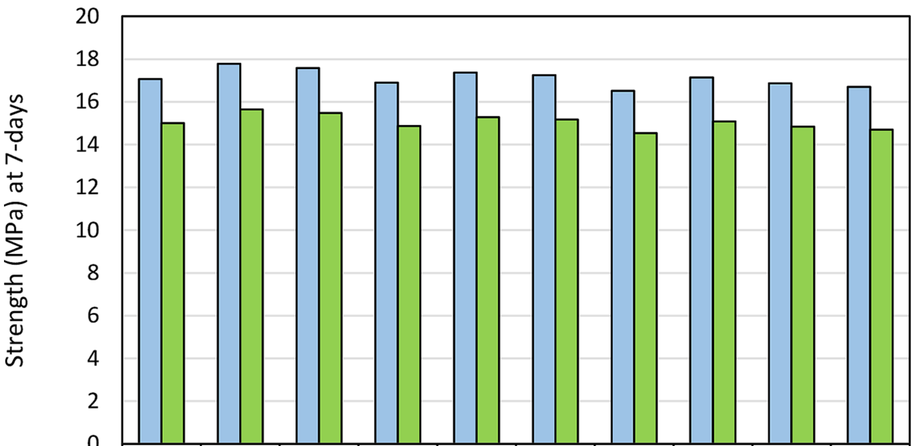


	B5	B10	B15	G5	G10	G15	T5	T10	T15
Compressive	4,9	3,5	-1,1	2,0	1,2	-3,8	1,5	-1,3	-4,6
Flexural	4,2	3,1	-0,9	1,8	1,1	-3,2	0,5	-1,1	-2,1
Tensile	4,50	3,2	-1,2	1,6	1,5	-3	0,8	-1	-2,5

Figure 4. Comparative between control mix and other mixes for strength results

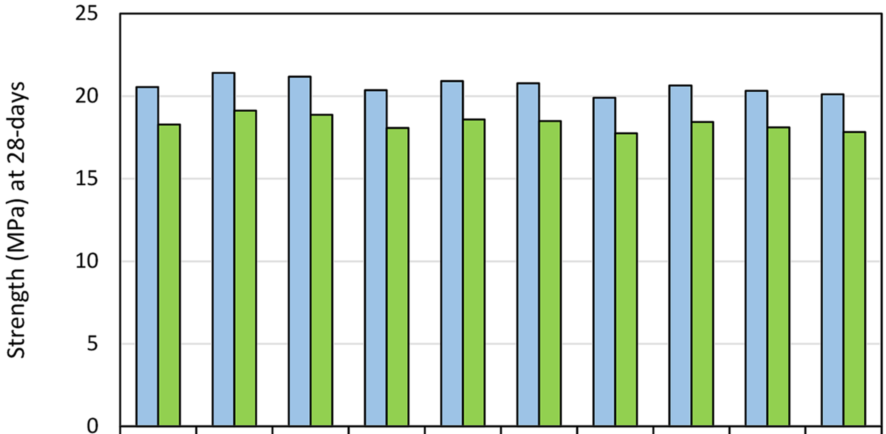
so still 5% gave better strength results than 10%, while 15% replacement led to a start of reduction strength (compressive, flexural, tensile) and that may be attributed to particle shape, activity and cementitious properties [Abbas, 2021; Abbas, 2022]. The 5% of terrazzo tile powder replacement of cement can be used with slight increase of strength of RPC mixture, when increasing to 10% or 5% the retardation of mixture was pronounced and that can be attributed to the effect of second layer of mortar and to the highly contaminated of terrazzo tile to old mortar bonding. That led to lower benefits of high fineness and activity silica in raw materials form. The flexural and tensile strength results at 7, 28 and 90 days presented in Figures 5, 6 and 7, respectively, showed a compatibility and homogeneity of results with compressive strength, since whenever compressive strength increase or decrease, the flexural and tensile strengths also follow the same trend and that supports the confidence of results, as presented in Figure 8 with statistical linear equation for all ages and high R2.

Finally, the use of 5% waste demolition recycled powder as clay brick, window glass and terrazzo tile showed the highest improvement in mechanical strength, so the 5% was the most safe recommendation replacement by weight of cement in RPC mixture. In turn, 10% also can be used carefully, since its result close to control mix.



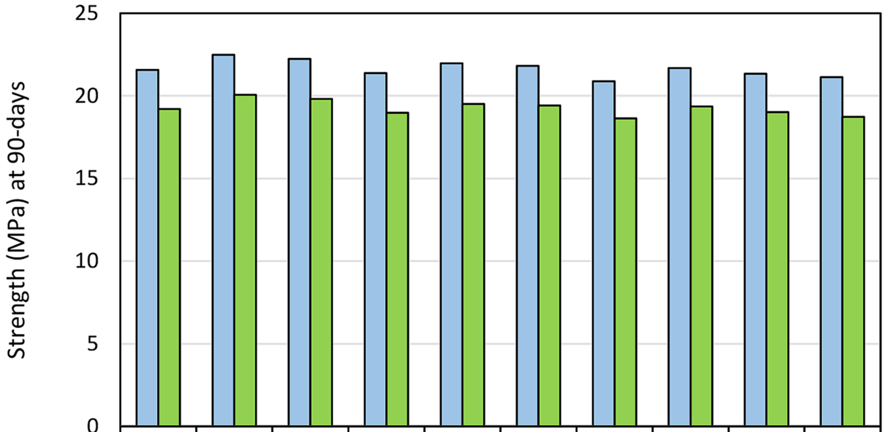
	Con.	B5	B10	B15	G5	G10	G15	T5	T10	T15
Flexural	17,06	17,77	17,59	16,90	17,36	17,24	16,51	17,14	16,87	16,70
Tensile	15,01	15,64	15,48	14,87	15,28	15,17	14,53	15,08	14,84	14,69

Figure 5. Flexural and tensile results for all mixes at 7-days



	Con.	B5	B10	B15	G5	G10	G15	T5	T10	T15
Flexural	20,55	21,41	21,19	20,37	20,92	20,78	19,89	20,65	20,32	20,12
Tensile	18,29	19,11	18,87	18,07	18,58	18,49	17,74	18,44	18,11	17,83

Figure 6. Flexural and tensile results for all mixes at 28-days



	Con.	B5	B10	B15	G5	G10	G15	T5	T10	T15
Flexural	21,58	22,48	22,25	21,38	21,97	21,81	20,89	21,69	21,34	21,12
Tensile	19,20	20,07	19,82	18,97	19,51	19,42	18,63	19,36	19,01	18,72

Figure 7. Flexural and tensile results for all mixes at 90-days

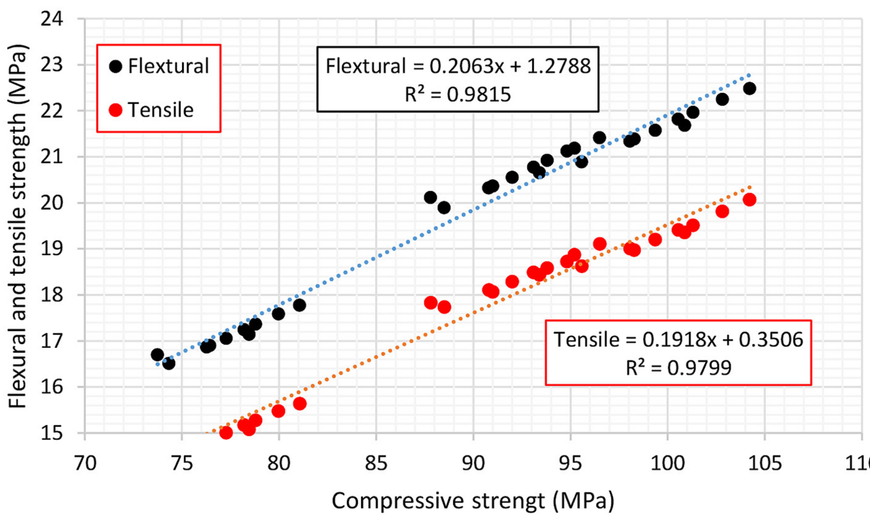


Figure 8. Statistical relation between compressive with flexural and tensile strength

CONCLUSIONS

The improvement strength of the RPC containing 5% of very fine powder waste materials (clay brick or window glass or terrazzo tile) as partial replacement of cement weight up to (4.9, 4.2, 4.5)%, (2, 1.8, 1.6)% and (1.5, 0.5, 0.8)% for (compressive – flexural –tensile), respectively, using B, G and T, respectively, at 28 days was achieved compared to the control mix. The 10% replacement of brick powder can show development in strength around 3% at 28/days, and slight enhancement around 1% for glass powder, while the results start to decrease slightly around 1% for tile powder. The 15% replacement showed a reduction in the strength of RPC mixture for all waste mixture, especially for tile powder. The 10% replacement of cement weight can be more effective to reduce cement consumption and dispose of more demolition waste materials with acceptable strength of the RPC. The efficiency of the adoption of curing cycle with percentage increase in compressive strength of more than 15% at 28 days was achieved for control mix.

REFERENCES

1. Abbas Z.K., Abbood A.A. 2021. The influence of incorporating recycled brick on concrete properties. InIOP Conference Series: Materials Science and Engineering. IOP Publishing, 1067(1), 012010.
2. Abbas Z.K., Abd S.K. 2021. Study of Using of Recycled Brick Waste (RBW) to produce Environmental Friendly Concrete: A Review. Journal of Engineering, 27(11), 1–4.
3. Abbas Z.K. 2022. Properties of Roller-Compacted Concrete Pavement Containing Different Waste Material Fillers. Journal of Engineering, 28(9), 86–106.
4. Abbas Z.K. 2022. Properties of Roller-Compacted Concrete Pavement Containing Different Waste Material Fillers. Journal of Engineering, 28(9), 86–106.
5. Abbas Z.K., Mahdi H.A., Tayeh B.A. 2021. Producing sustainable concrete using nano recycled glass. The Open Civil Engineering Journal, 15(1).
6. Abbas Zena K., Abbood Ahlam A., Mahmood Raghad S. 2022. Producing low-cost self-consolidation concrete using sustainable material. Open Engineering, 12(1), 850–858. https://doi.org/10.1515/eng-2022-0368
7. Abdullah D.J., Abbas Z.K., Abed S.K. 2022. Some properties of concrete containing waste brick as partial replacement of coarse aggregate and addition of nano brick powder. In: IOP Conference Series: Earth and Environmental Science, 961(1), 012093.
8. Ahmad S., Al-Amoudi O.S., Khan S.M., 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, 1, 17:e01255.
9. Al-Anbori Z.K., Al-Obaidi A.A. 2016. Some mechanical properties of concrete by using manufactured blended cement with grinded local rocks. Journal of Engineering, 22(3), 1–21.
10. Al-Hassani H.M., Khalil W.I., Danha L.S. 2015. Prediction of the nominal bending moment capacity for plain and singly reinforced rectangular RPC beam sections. Engineering and Technology Journal, 33(5), 1113–30.
11. Al-Hubboubi S.K., Abbas Z.K. 2018. Regression Analysis Models to predict the 28-day Compressive Strength Using Accelerated Curing Tests. Journal of Engineering, 24(1), 1–9.
12. Al-Mansour A., Chow C.L., Feo L., Penna R., Lau D. 2019. Green concrete: By-products utilization and advanced approaches. Sustainability, 11(19), 5145.
13. ASTM C 78. 2016. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), ASTM International.
14. ASTM C1240. 2015. Standard Specification for Silica Fume Used in Cementitious Mixtures (PA ed.). West Conshohocken: American Society for Testing and Materials.
15. ASTM C192/C192M-16a. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. ASTM International.
16. ASTM C494/C 494M-08a. Standard Specification for Chemical Admixtures for Concrete, ASTM International.
17. ASTM C496/C 496M-11. Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International.
18. ASTM C618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
19. ASTM C618-17a. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International.
20. British Standard Institution. 1983. Methods for making test cubes from fresh concrete, BS 1881: Part 108: 1983.
21. BS EN 12390-3. 2019. Method for determination of compressive strength of concrete cubes. British Standard.
22. Iraqi specification, No. 5, 2019, Portland Cement, Ministry of Planning, Central Organization for Standardization and Quality Control.
23. Iraqi Specifications, No. 45, 1984. The Used Aggregate from Natural Sources in Concrete and Building, Central Apparatus for Standardization and Quality Control.

24. Kasaniya M., Thomas M.D., Moffatt E.G. 2021. Pozzolanic reactivity of natural pozzolans, ground glasses and coal bottom ashes and implication of their incorporation on the chloride permeability of concrete. Cement and Concrete Research, 139, 106259.
25. Khitab A., Kırgız M.S., Nehdi M.L., Mirza J., de Sousa Galdino A.G., Pour A.K. 2022. Mechanical, thermal, durability and microstructural behavior of hybrid waste-modified green reactive powder concrete. Construction and Building Materials, 344, 128184.
26. Khreef S.M., Abbas Z.K. 2021. Investigation the Quality of the Treatment Sand from Sulfite using Magnetic Water in Reactive Powder Concrete. InIOP Conference Series: Materials Science and Engineering. IOP Publishing, 1094(1), 012057.
27. Khreef S.M., Abbas Z.K. 2021. The effects of using magnetized water in reactive powder concrete with different curing methods. InIOP Conference Series: Materials Science and Engineering, IOP Publishing, 1067(1), 012017.
28. Liu S.G., Xiang Z., Huang R.H., Wang D.H., Ju Y.Z. 2019. The durability of reactive powder concrete: a review. In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 474(1), 012047.
29. Mishra A., Chandraul K., Singh M. 2017. Experimental study on steel fiber reinforced concrete. International Research Journal of Engineering and Technology (IRJET), 4(11), 895–8.
30. Qasim M.F., Abbas Z.K., Abed S.K. 2021. Producing Green Concrete with Plastic Waste and Nano Silica Sand. Engineering, Technology & Applied Science Research, 11(6), 7932–7.
31. Shannag M.J., Yeginobali A. 1995. Properties of pastes, mortars and concretes containing natural pozzolan. Cement and Concrete Research, 25(3), 647–57.
32. Shannag M.J. 2000. High strength concrete containing natural pozzolan and silica fume. Cement and concrete composites, 22(6), 399–406.
33. Singh H. 2017. Construction Practice. In Steel Fiber Reinforced Concrete 2017. Springer, Singapore, 159–165.
34. Sivakrishna A., Adesina A., Awoyera P.O., Kumar K.R. 2020. Green concrete: A review of recent developments. Materials Today: Proceedings, 27, 54–58.
35. Suhendro B. 2014. Toward green concrete for better sustainable environment. Procedia Engineering, 95, 305–20.