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Effect of Partial Replacement of Cement with Ceramic Waste and Discarded Tyre as Coarse Aggregate on the Properties of Concrete

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ABSTRACT

Concrete is a composite construction material formed by combining a binder (cement or lime) with fine and coarse aggregate, water, and, where required, admixtures; its strength and quality depend heavily on the proportions used in the mix. Because concrete is the most widely used construction material by tonnage, extensive research has examined the effects of partially or fully replacing its constituents with alternative and waste materials. This study investigated the effect of partially replacing cement with ceramic waste and coarse aggregate with discarded (shredded) tyre on the fresh and hardened properties of concrete. Ceramic waste was substituted for cement and shredded tyre was substituted for coarse aggregate at replacement levels of 0%, 5%, 10%, 15%, and 20%, across all combinations of the two materials. Concrete cubes were cast for each mix, cured, and crushed at 7, 14, 21, and 28 days to determine compressive strength development. Regression analysis was performed on the 28-day (ultimate) strength values to establish a mathematical relationship between percentage ceramic waste replacement and compressive strength at each fixed tyre-replacement level. The regression equations indicate that compressive strength decreased consistently as the proportion of either ceramic waste or discarded tyre increased. These findings suggest that, while ceramic waste and discarded tyre can be incorporated into concrete as partial replacement materials, their proportions should be limited and optimized to avoid unacceptable strength loss, particularly in structural applications.

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INTRODUCTION

Concrete is an artificial, stone-like composite material produced by mixing a binder (cement or lime) with aggregate (sand, gravel, crushed stone, or brick chips), water, and, optionally, admixtures in specific proportions. The strength and quality of the resulting material depend on these mixing proportions and can be summarized as Concrete = Binding Material + Fine and Coarse Aggregate + Water + Admixture (optional) (Sekar, 2017; Obande & Chiadighikaobi, 2026). The physical properties desired in the finished material can be further tailored by adding additives and reinforcement to the mixture (Ramanaidu & Murahari Krishna, 2018). When mixed in the correct proportions, these ingredients form a solid mass that can be readily moulded into a desired shape and, over time, hardens into a rigid, durable material used extensively in buildings, pavements, and other infrastructure.

Concrete technology was adopted on a large scale by the ancient Romans, most notably in the construction of the Colosseum and the dome of the Pantheon, which remains the world's largest unreinforced concrete structure (Ramanaidu & Murahari Krishna, 2018; Sekar, 2017; Obande & Chiadighikaobi, 2026). Following a decline after the fall of the Roman Empire, concrete technology was re-pioneered and is today the most widely used human-made material by tonnage (Ramanaidu & Murahari Krishna,

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2018). Because of this widespread use, extensive research has been carried out on the full or partial replacement of concrete's constituent materials with alternative or waste materials. For example, Dilip and Amitava (2012) examined the partial replacement of cement with silica fume and found that it produced concrete that was flowable yet cohesive, with improved early- and later-age strength and resistance to aggressive environments. Similarly, Harshit et al. (2025) investigated the partial replacement of cement with polymethyl methacrylate and found that a 4% replacement level produced the highest cube strength.

A wide range of other supplementary cementitious materials has been investigated on similar terms. Basha and Bezawada (2023) found that rice husk ash used at a 15% cement replacement level improved the mechanical properties and chloride-related durability of concrete relative to a referral mix, while Marthong (2012) reported that rice husk ash increased water demand and setting time and reduced workability as the replacement level rose, even though it also reduced water absorption up to a 20% replacement level. Getahun and Bewket (2021) similarly found that cattle bone ash, owing to its high calcium oxide content, could partially replace cement while measurably affecting the setting time, soundness, and compressive strength of the resulting concrete. These studies establish a broader pattern, consistent with the present study, in which alternative and waste-derived cementitious materials can substitute for a portion of cement but generally alter workability and strength development in ways that must be optimized rather than maximized.

Ceramic waste specifically has attracted considerable research attention as both a cement and an aggregate replacement. In a review of the literature on waste ceramics in concrete, Meena et al. (2022) reported that incorporating waste ceramic material generally decreases both fresh and hardened concrete density, with the reduction scaling roughly linearly with ceramic content, while compressive, flexural, and split tensile strength can remain comparable to or slightly exceed that of reference concrete at moderate replacement levels, although water absorption tends to increase. Uniyal and Singh (2019) likewise found that an optimal dosage of ceramic tile powder as a partial cement replacement improved compressive strength, while excessive replacement was detrimental.

Praveen Kumar and Chandrasekhar Reddy (2017) evaluated the durability of concrete containing ceramic waste as a cement replacement and found satisfactory workability and compressive strength up to a 20% replacement level, concluding that this level had potential for use in concrete block production. Daniel and Raju (2018) reported that the flexural strength of concrete containing ceramic waste powder improved up to a 15% cement replacement level, beyond which performance declined — a pattern of diminishing returns at higher replacement levels that is consistent with the strength trends obtained in the present study.

The use of discarded tyre rubber as a partial aggregate replacement has also been studied extensively, most notably in the foundational work of Khatib and Bayomy (1999), who investigated rubberized Portland cement concrete containing fine crumb rubber and coarse tyre chips as partial replacements for natural aggregate. They found that slump decreased sharply as rubber content increased — approaching zero workability by hand compaction at around 40% rubber content by aggregate volume — and that both compressive and flexural strength declined non-linearly with increasing rubber content, while air content increased. These findings anticipate the workability and strength trends observed for the discarded-tyre component of the present study. Building on this body of work, the present study examines the combined effect of partially replacing cement with ceramic waste and coarse aggregate with discarded (shredded) tyre on the fresh and hardened properties of concrete.

MATERIALS AND METHODS

Materials and Mix Design

Ordinary Portland cement, natural fine aggregate (sand), natural coarse aggregate (crushed granite), potable water, ceramic waste

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(obtained from discarded ceramic tiles, crushed and graded to replace cement by mass), and discarded (shredded) vehicle tyre (graded to replace coarse aggregate by volume) were used in this study.

Concrete cubes were cast at a control mix (0% ceramic waste, 0% tyre) and at partial replacement levels of 5%, 10%, 15%, and 20% for both ceramic waste (replacing cement) and discarded tyre (replacing coarse aggregate), covering all combinations of the two variables. This produced 25 distinct mix combinations, denoted throughout this paper as (% ceramic waste, % discarded tyre).

Figure 1. Mixture of cement + ceramic waste, fine aggregate, and coarse aggregate + shredded tyre

Figure 2. Compacting factor test

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Table 1. Percentage mix proportions of ceramic waste and discarded tyre used for each cube set

EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH CERAMICS WASTE AND DISCARDED							
SPECIMEN ID	CERAMICS+ CEMENT			FINE AGGREGATE	CRUSH ROCK + TYRE CONTENT(%)		
	CERAMICS (%)	CEMENT (%)	TOTAL (%)		ROCK (%)	TYRE (%)	TOTAL (%)
0% DT , 0% CW	0	100	100	100	0	100	100
0% DT , 5% CW	5	95	100	100	0	100	100
0% DT , 10% CW	10	90	100	100	0	100	100
0% DT , 15% CW	15	85	100	100	0	100	100
0% DT , 20% CW	20	80	100	100	0	100	100
5% DT , 0% CW	0	100	100	100	5	95	100
5% DT , 5% CW	5	95	100	100	5	95	100
5% DT , 10% CW	10	90	100	100	5	95	100
5% DT , 15% CW	15	85	100	100	5	95	100
5% DT , 20% CW	20	80	100	100	5	95	100
10% DT , 0% CW	0	100	100	100	10	90	100
10% DT , 5% CW	5	95	100	100	10	90	100
10% DT , 10% CW	10	90	100	100	10	90	100
10% DT , 15% CW	15	85	100	100	10	90	100
10% DT , 20% CW	20	80	100	100	10	90	100
15% DT , 0% CW	0	100	100	100	15	85	100
15% DT , 5% CW	5	95	100	100	15	85	100
15% DT , 10% CW	10	90	100	100	15	85	100
15% DT , 15% CW	15	85	100	100	15	85	100
15% DT , 20% CW	20	80	100	100	15	85	100
20% DT , 0% CW	0	100	100	100	20	80	100
20% DT , 5% CW	5	95	100	100	20	80	100
20% DT , 10% CW	10	90	100	100	20	80	100
20% DT , 15% CW	15	85	100	100	20	80	100

Sample Preparation and Curing

For each of the 25 mix combinations, 12 concrete cubes were cast. Of these, three cubes were crushed at each of 7, 14, 21, and 28 days to determine compressive strength development with age. In addition, two cubes from each set were reserved for fire-resistance testing and two for ductility testing. All results were tabulated according to mix proportion and curing age.

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Figure 3. Concrete cubes before demoulding

Figure 4. Curing of cubes

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Figure 5. Crushing of cubes

Testing Program

The testing program comprised: oxide composition analysis of the ceramic waste; particle size (sieve) analysis, moisture content, and specific gravity determination for both fine and coarse aggregate; slump and compacting-factor tests on the fresh concrete for each mix; and compressive strength testing of hardened cubes at 7, 14, 21, and 28 days. Regression analysis was subsequently applied to the 28-day compressive strength results to determine the mathematical relationship between percentage ceramic waste replacement and strength at each fixed level of tyre replacement.

RESULTS AND DISCUSSION

Chemical Composition of Ceramic Waste

The oxide composition of the ceramic waste used in this study, determined by X-ray fluorescence, is presented in Table 2. Silica (SiO_2) was the dominant oxide at 56.04%, followed by alumina (Al_2O_3) at 16.38% and lime (CaO) at 12.18%, indicating a broadly pozzolanic composition consistent with values reported for ceramic waste in prior studies.

Table 2: Oxide Composition of Ceramic Waste

S/N	Elemental Oxide	% Composition
1	CaO	12.18
2	SiO_2	56.04
3	Al_2O_3	16.38
4	Fe_2O_3	4.88
5	MgO	3.73
6	SO_3	2.08

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S/N	Elemental Oxide	% Composition
7	Na2O	1.37
8	K2O	3.09
9	P2O5	0.18
10	TiO2	0.58
11	MnO	0.15
12	Loss on Ignition	0.00

Aggregate Properties

Fine Aggregate. Table 3 presents the particle size distribution of the fine aggregate. The fine aggregate was predominantly retained between the 0.212 mm and 0.15 mm sieves, with 12.44% passing the 0.15 mm sieve and 5.14% passing the 0.075 mm sieve, indicating a well-graded medium sand consistent with typical concreting sand gradation.

Table 3: Particle Size Analysis of Fine Aggregate

Sieve Size (mm)	Weight Retained (g)	% Weight Retained	Cumulative % Retained	% Passing
4.77	0.00	0.00	0.00	100.00
2.35	0.00	0.00	0.00	100.00
1.18	0.00	0.00	0.00	100.00
0.60	1.71	0.34	0.34	99.65
0.425	1.60	0.32	0.66	99.34
0.30	9.20	1.84	2.50	97.30
0.212	92.60	18.52	21.02	79.98
0.15	332.70	66.54	87.56	12.44
0.075	36.60	7.32	94.88	5.14
Pan	5.60	1.12	96.00	4.00

Coarse Aggregate. The particle size distribution of the coarse aggregate is presented in Table 4.

Table 4: Particle Size Analysis of Coarse Aggregate

Sieve Size (mm)	Weight Retained (g)	Cumulative Value	% Passing
19	0	500	100
13.5	112	388	77.7
9.5	235	154	30.5
4.75	67	87	17.3

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Sieve Size (mm)	Weight Retained (g)	Cumulative Value	% Passing
2.56	43	43	8.6
1.18	10	33	6.6
0.60	6	26	5.3
0.30	7	20	4.0
0.15	9	12	2.2
0.075	1.1	9.8	1.97

Moisture Content and Specific Gravity of Aggregates

Fine Aggregate:

The moisture content of the fine aggregate was determined on three samples (KC, MB, and UF), giving individual moisture contents of 6.34%, 8.71%, and 12.52% respectively. The specific gravity of the fine aggregate was determined by the pycnometer method.

Coarse Aggregate:

The specific gravity of the coarse aggregate was likewise determined by the pycnometer method. The moisture content of the coarse aggregate was determined on three samples (AC, B2, and QM), giving individual values of 4.31%, 4.65%, and 4.09% respectively.

Fresh Concrete Properties

Table 5 presents the slump and compacting-factor results for the fresh concrete at each of the 25 mix combinations, expressed as (% ceramic waste, % discarded tyre). Compacting factor values ranged from 0.81 to 0.95, and slump values ranged from 6 mm to 29 mm, indicating a generally low- to medium-workability mix across all replacement levels typical of a low water-cement-ratio structural concrete. This general reduction in workability at higher discarded-tyre content is consistent with Khatib and Bayomy (1999), who reported a sharp decline in slump with increasing rubber aggregate content in rubberized Portland cement concrete.

Table 5: Slump and Compacting Factor of Fresh Concrete by Mix Proportion

% Ceramic Waste, % Discarded Tyre	Weight of Partially Compacted Concrete (g)	Weight of Fully Compacted Concrete (g)	Compacting Factor	Slump (mm)	Slump Type
0, 0	15535	17163	0.91	10	Zero
0, 5	15428	17072	0.90	9	Zero
0, 10	14620	17046	0.86	8	Zero
0, 15	15042	17072	0.88	20	Zero
0, 20	15532	17022	0.91	28	Zero
5, 0	15046	17056	0.88	29	Zero
5, 5	15038	16547	0.91	10	Zero
5, 10	14857	16717	0.89	9	Zero

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% Ceramic Waste, % Discarded Tyre	Weight of Partially Compacted Concrete (g)	Weight of Fully Compacted Concrete (g)	Compacting Factor	Slump (mm)	Slump Type
5, 15	14846	16720	0.89	10	Zero
5, 20	14856	16578	0.90	10	Zero
10, 0	14845	16648	0.89	9	Zero
10, 5	14398	16385	0.88	6	Zero
10, 10	14308	16345	0.88	15	Zero
10, 15	14208	16340	0.87	14	Zero
10, 20	13659	16343	0.84	10	Zero
15, 0	14533	16382	0.89	10	Zero
15, 5	13876	16068	0.86	9	Zero
15, 10	13826	17085	0.81	11	Zero
15, 15	13829	16306	0.85	10	Zero
15, 20	13566	16095	0.84	10	Zero
20, 0	14140	16130	0.88	9	Zero
20, 5	14600	15848	0.92	10	Zero
20, 10	14055	15662	0.90	10	Zero
20, 15	14340	16062	0.89	10	Zero
20, 20	15190	16010	0.95	14	Zero

Hardened Concrete Properties: Compressive Strength

Compressive strength testing was carried out on cubes crushed at 7, 14, 21, and 28 days (see Table 6) for each of the 25 mix combinations, and regression analysis was applied to the 28-day (ultimate) strength results at each fixed tyre-replacement level to determine the relationship between percentage ceramic waste replacement and strength (see Figure 6)

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Table 6. Compressive strength (MPa) at 7, 14, 21, and 28 days by mix proportion

SPECIMEN ID		DATE CASTED	DATE TESTED	AGE AT TESTING (Days)	MASS OF SPECIMEN (g)	AVE. MASS OF SPECEMEN (g)	DENSITY OF SPECIMEN	LOAD AT FAILURE (KN)	AVE. LOAD AT FAILURE	STRENGTH (N/mm²)
0% DT , 0% CW	1	14-11-23	21-11-23	7	2586			230		
	2	14-11-23	21-11-23	7	2515	2540.0	25.4	235	235	23.50
	3	14-11-23	21-11-23	7	2519			240		
	4	14-11-23	28-11-23	14	2536			328		
	5	14-11-23	28-11-23	14	2470	2515.7	25.2	329	329	32.87
	6	14-11-23	28-11-23	14	2541			329		
	7	14-11-23	5-12-23	21	2573			340		
	8	14-11-23	5-12-23	21	2587	2569.7	25.7	340	340	34.00
	9	14-11-23	5-12-23	21	2549			340		
	10	14-11-23	12-12-23	28	2598			361		
	11	14-11-23	12-12-23	28	2569	2580.7	25.8	360	360	36.03
	12	14-11-23	12-12-23	28	2575			360		
0% DT , 5% CW	13	14-11-23	21-11-23	7	2652			235		
	14	14-11-23	21-11-23	7	2687	2668.0	26.7	231	233	23.33
	15	14-11-23	21-11-23	7	2665			234		
	16	14-11-23	28-11-23	14	2587			346		
	17	14-11-23	28-11-23	14	2589	2579.0	25.8	352	348	34.83
	18	14-11-23	28-11-23	14	2561			347		
	19	14-11-23	5-12-23	21	2490			360		
	20	14-11-23	5-12-23	21	2419	2469.7	24.7	359	360	35.97
	21	14-11-23	5-12-23	21	2500			360		
	22	14-11-23	12-12-23	28	2505			360		
	23	14-11-23	12-12-23	28	2552	2551.7	25.5	361	361	36.10
	24	14-11-23	12-12-23	28	2598			362		
10% CW	25	14-11-23	21-11-23	7	2626			236		
	26	14-11-23	21-11-23	7	2519	2560.7	25.6	234	234	23.37
	27	14-11-23	21-11-23	7	2537			231		
	28	14-11-23	28-11-23	14	2569			338		
	29	14-11-23	28-11-23	14	2526	2553.7	25.5	340	340	33.97
	30	14-11-23	28-11-23	14	2566			341		

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0% DT ,	31	14-11-23	5-12-23	21	2510	2511.7	25.1	351	351	35.10
	32	14-11-23	5-12-23	21	2520			351		
	33	14-11-23	5-12-23	21	2505			351		
	34	14-11-23	12-12-23	28	2538	2560.0	25.6	349	349	34.93
	35	14-11-23	12-12-23	28	2552			349		
	36	14-11-23	12-12-23	28	2590			350		
0% DT , 15% CW	37	14-11-23	21-11-23	7	2616	2591.3	25.9	233	233	23.30
	38	14-11-23	21-11-23	7	2595			232		
	39	14-11-23	21-11-23	7	2563			234		
	40	14-11-23	28-11-23	14	2536	2542.3	25.4	341	337	33.67
	41	14-11-23	28-11-23	14	2515			340		
	42	14-11-23	28-11-23	14	2576			329		
	43	14-11-23	5-12-23	21	2526	2455.3	24.6	347	348	34.77
	44	14-11-23	5-12-23	21	2409			348		
	45	14-11-23	5-12-23	21	2431			348		
	46	14-11-23	12-12-23	28	2490	2501.7	25.0	348	348	34.83
	47	14-11-23	12-12-23	28	2510			348		
	48	14-11-23	12-12-23	28	2505			349		
0% DT , 20% CW	49	15-11-23	22-11-23	7	2450	2457.0	24.6	231	231	23.13
	50	15-11-23	22-11-23	7	2446			232		
	51	15-11-23	22-11-23	7	2475			231		
	52	15-11-23	29-11-23	14	2495	2616.3	26.2	323	311	31.10
	53	15-11-23	29-11-23	14	2668			304		
	54	15-11-23	29-11-23	14	2686			306		
	55	15-11-23	6-12-23	21	2526	2478.7	24.8	320	318	31.77
	56	15-11-23	6-12-23	21	2425			320		
	57	15-11-23	6-12-23	21	2485			313		
	58	15-11-23	13-12-23	28	2575	2537.3	25.4	319	319	31.87
	59	15-11-23	13-12-23	28	2522			319		
	60	15-11-23	13-12-23	28	2515			318		
	61	15-11-23	22-11-23	7	2504	2472.7	24.7	199	198	19.83
	62	15-11-23	22-11-23	7	2507			198		
	63	15-11-23	22-11-23	7	2407			198		
	64	15-11-23	29-11-23	14	2465			282		

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5% DT , 0% CW	65	15-11-23	29-11-23	14	2496	2498.7	25.0	283	283	28.30
	66	15-11-23	29-11-23	14	2535			284		
	67	15-11-23	6-12-23	21	2434			292		
	68	15-11-23	6-12-23	21	2451	2443.7	24.4	292	292	29.17
	69	15-11-23	6-12-23	21	2446			291		
	70	15-11-23	13-12-23	28	2465			310		
	71	15-11-23	13-12-23	28	2447	2461.7	24.6	311	311	31.07
	72	15-11-23	13-12-23	28	2473			311		
5% DT , 5% CW	73	15-11-23	22-11-23	7	2456			207		
	74	15-11-23	22-11-23	7	2356	2400.0	24.0	208	208	20.77
	75	15-11-23	22-11-23	7	2388			208		
	76	15-11-23	29-11-23	14	2461			292		
	77	15-11-23	29-11-23	14	2469	2484.0	24.8	291	291	29.13
	78	15-11-23	29-11-23	14	2522			291		
	79	15-11-23	6-12-23	21	2446			300		
	80	15-11-23	6-12-23	21	2435	2437.7	24.4	300	301	30.07
	81	15-11-23	6-12-23	21	2432			302		
	82	15-11-23	13-12-23	28	2469			321		
	83	15-11-23	13-12-23	28	2461	2455.3	24.6	320	320	32.03
	84	15-11-23	13-12-23	28	2436			320		
5% DT , 10% CW	85	15-11-23	22-11-23	7	2465			205		
	86	15-11-23	22-11-23	7	2423	2454.7	24.5	206	205	20.53
	87	15-11-23	22-11-23	7	2476			205		
	88	15-11-23	29-11-23	14	2463			289		
	89	15-11-23	29-11-23	14	2427	2441.0	24.4	288	288	28.80
	90	15-11-23	29-11-23	14	2433			287		
	91	15-11-23	6-12-23	21	2466			300		
	92	15-11-23	6-12-23	21	2467	2446.3	24.5	299	299	29.93
	93	15-11-23	6-12-23	21	2406			299		
	94	15-11-23	13-12-23	28	2447			318		
	95	15-11-23	13-12-23	28	2465	2459.3	24.6	319	319	31.87
	96	15-11-23	13-12-23	28	2466			319		
	97	16-11-23	23-11-23	7	2466			168		
	98	16-11-23	23-11-23	7	2492	2474.7	24.7	168	168	16.80

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JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(2), JUNE, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

5% DT , 15% CW	99	16-11-23	23-11-23	7	2466			168		
	100	16-11-23	30-11-23	14	2459			234		
	101	16-11-23	30-11-23	14	2449	2451.3	24.5	234	234	23.40
	102	16-11-23	30-11-23	14	2446			234		
	103	16-11-23	7-12-23	21	2426			243		
	104	16-11-23	7-12-23	21	2446	2482.3	24.8	244	244	24.37
	105	16-11-23	7-12-23	21	2575			244		
	106	16-11-23	14-12-23	28	2482			259		
	107	16-11-23	14-12-23	28	2343	2431.3	24.3	259	259	25.87
	108	16-11-23	14-12-23	28	2469			258		
5% DT , 20% CW	109	16-11-23	23-11-23	7	2426			186		
	110	16-11-23	23-11-23	7	2426	2456.7	24.6	188	187	18.73
	111	16-11-23	23-11-23	7	2518			188		
	112	16-11-23	30-11-23	14	2466			261		
	113	16-11-23	30-11-23	14	2483	2470.3	24.7	262	262	26.17
	114	16-11-23	30-11-23	14	2462			262		
	115	16-11-23	7-12-23	21	2432			269		
	116	16-11-23	7-12-23	21	2426	2434.3	24.3	269	269	26.90
	117	16-11-23	7-12-23	21	2445			269		
	118	16-11-23	14-12-23	28	2467			285		
	119	16-11-23	14-12-23	28	2499	2497.3	25.0	285	285	28.50
	120	16-11-23	14-12-23	28	2526			285		
10% DT , 0% CW	121	16-11-23	23-11-23	7	2345			144		
	122	16-11-23	23-11-23	7	2317	2345.7	23.5	145	145	14.47
	123	16-11-23	23-11-23	7	2375			145		
	124	16-11-23	30-11-23	14	2453			219		
	125	16-11-23	30-11-23	14	2316	2378.3	23.8	220	220	21.97
	126	16-11-23	30-11-23	14	2366			220		
	127	16-11-23	7-12-23	21	2446			234		
	128	16-11-23	7-12-23	21	2327	2387.3	23.9	235	235	23.47
	129	16-11-23	7-12-23	21	2389			235		
	130	16-11-23	14-12-23	28	2456			241		
	131	16-11-23	14-12-23	28	2499	2478.0	24.8	241	241	24.10
	132	16-11-23	14-12-23	28	2479			241		

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JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(2), JUNE, 2026
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10% DT , 5% CW	133	16-11-23	23-11-23	7	2275			157		
	134	16-11-23	23-11-23	7	2282	2317.7	23.2	157	157	15.70
	135	16-11-23	23-11-23	7	2396			157		
	136	16-11-23	30-11-23	14	2367			209		
	137	16-11-23	30-11-23	14	2465	2384.7	23.8	209	209	20.93
	138	16-11-23	30-11-23	14	2322			210		
	139	16-11-23	7-12-23	21	2432			211		
	140	16-11-23	7-12-23	21	2447	2441.7	24.4	211	211	21.13
	141	16-11-23	7-12-23	21	2446			212		
	142	16-11-23	14-12-23	28	2496			225		
	143	16-11-23	14-12-23	28	2422	2457.0	24.6	225	225	22.47
	144	16-11-23	14-12-23	28	2453			224		
10% DT , 10% CW	145	17-11-23	24-11-23	7	2342			156		
	146	17-11-23	24-11-23	7	2306	2340.0	23.4	157	157	15.67
	147	17-11-23	24-11-23	7	2372			157		
	148	17-11-23	1-12-23	14	2350			206		
	149	17-11-23	1-12-23	14	2391	2361.0	23.6	205	205	20.50
	150	17-11-23	1-12-23	14	2342			204		
	151	17-11-23	8-12-23	21	2334			211		
	152	17-11-23	8-12-23	21	2496	2445.3	24.5	212	212	21.20
	153	17-11-23	8-12-23	21	2506			213		
	154	17-11-23	15-12-23	28	2420			224		
	155	17-11-23	15-12-23	28	2402	2376.7	23.8	225	225	22.47
	156	17-11-23	15-12-23	28	2308			225		
10% DT , 15% CW	157	17-11-23	24-11-23	7	2343			150		
	158	17-11-23	24-11-23	7	2316	2347.0	23.5	151	152	15.17
	159	17-11-23	24-11-23	7	2382			154		
	160	17-11-23	1-12-23	14	2306			192		
	161	17-11-23	1-12-23	14	2286	2352.7	23.5	193	193	19.30
	162	17-11-23	1-12-23	14	2466			194		
	163	17-11-23	8-12-23	21	2416			199		
	164	17-11-23	8-12-23	21	2356	2406.0	24.1	199	200	20.00
	165	17-11-23	8-12-23	21	2446			202		
	166	17-11-23	15-12-23	28	2446			212		

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JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(2), JUNE, 2026
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	167	17-11-23	15-12-23	28	2428	2404.0	24.0	212	213	21.27
	168	17-11-23	15-12-23	28	2338			214		
10% DT , 20% CW	169	17-11-23	24-11-23	7	2324			135		
	170	17-11-23	24-11-23	7	2306	2322.0	23.2	136	135	13.53
	171	17-11-23	24-11-23	7	2336			135		
	172	17-11-23	1-12-23	14	2342			178		
	173	17-11-23	1-12-23	14	2346	2344.3	23.4	178	178	17.77
	174	17-11-23	1-12-23	14	2345			177		
	175	17-11-23	8-12-23	21	2313			185		
	176	17-11-23	8-12-23	21	2268	2292.3	22.9	186	186	18.60
	177	17-11-23	8-12-23	21	2296			187		
	178	17-11-23	15-12-23	28	2448			192		
	179	17-11-23	15-12-23	28	2482	2419.3	24.2	193	193	19.30
	180	17-11-23	15-12-23	28	2328			194		
15% DT , 0% CW	181	17-11-23	24-11-23	7	2320			131		
	182	17-11-23	24-11-23	7	2390	2366.3	23.7	132	132	13.17
	183	17-11-23	24-11-23	7	2389			132		
	184	17-11-23	1-12-23	14	2349			181		
	185	17-11-23	1-12-23	14	2458	2387.7	23.9	182	182	18.17
	186	17-11-23	1-12-23	14	2356			182		
	187	17-11-23	8-12-23	21	2353			192		
	188	17-11-23	8-12-23	21	2282	2294.7	22.9	191	192	19.17
	189	17-11-23	8-12-23	21	2249			192		
	190	17-11-23	15-12-23	28	2316			195		
	191	17-11-23	15-12-23	28	2342	2313.3	23.1	195	195	19.50
	192	17-11-23	15-12-23	28	2282			195		
.5% DT , 5% CW	193	18-11-23	25-11-23	7	2399			101		
	194	18-11-23	25-11-23	7	2378	2381.0	23.8	102	101	10.13
	195	18-11-23	25-11-23	7	2366			101		
	196	18-11-23	2-12-23	14	2358			141		
	197	18-11-23	2-12-23	14	2348	2388.3	23.9	141	141	14.13
	198	18-11-23	2-12-23	14	2459			142		
	199	18-11-23	9-12-23	21	2379			147		
	200	18-11-23	9-12-23	21	2486	2431.0	24.3	146	147	14.67

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1	201	18-11-23	9-12-23	21	2428			147		
	202	18-11-23	16-12-23	28	2338	2391.3	23.9	155	156	15.63
	203	18-11-23	16-12-23	28	2382			155		
	204	18-11-23	16-12-23	28	2454			159		
15% DT , 10% CW	205	18-11-23	25-11-23	7	2238	2277.7	22.8	107	108	10.77
	206	18-11-23	25-11-23	7	2339			107		
	207	18-11-23	25-11-23	7	2256			109		
	208	18-11-23	2-12-23	14	2328	2346.7	23.5	150	151	15.13
	209	18-11-23	2-12-23	14	2316			152		
	210	18-11-23	2-12-23	14	2396			152		
	211	18-11-23	9-12-23	21	2338	2293.3	22.9	155	156	15.60
	212	18-11-23	9-12-23	21	2246			155		
	213	18-11-23	9-12-23	21	2296			158		
	214	18-11-23	16-12-23	28	2239	2271.7	22.7	165	165	16.53
	215	18-11-23	16-12-23	28	2356			164		
	216	18-11-23	16-12-23	28	2220			167		
15% DT , 15% CW	217	18-11-23	25-11-23	7	2316	2310.3	23.1	106	108	10.77
	218	18-11-23	25-11-23	7	2269			109		
	219	18-11-23	25-11-23	7	2346			108		
	220	18-11-23	2-12-23	14	2386	2344.7	23.4	148	147	14.70
	221	18-11-23	2-12-23	14	2259			147		
	222	18-11-23	2-12-23	14	2389			146		
	223	18-11-23	9-12-23	21	2266	2266.0	22.7	153	154	15.40
	224	18-11-23	9-12-23	21	2276			155		
	225	18-11-23	9-12-23	21	2256			154		
	226	18-11-23	16-12-23	28	2296	2308.0	23.1	164	165	16.53
	227	18-11-23	16-12-23	28	2218			165		
	228	18-11-23	16-12-23	28	2410			167		
20% CW	229	18-11-23	25-11-23	7	2359	2345.7	23.5	112	112	11.20
	230	18-11-23	25-11-23	7	2340			114		
	231	18-11-23	25-11-23	7	2338			110		
	232	18-11-23	2-12-23	14	2480	2432.3	24.3	153	156	15.60
	233	18-11-23	2-12-23	14	2408			158		
	234	18-11-23	2-12-23	14	2409			157		

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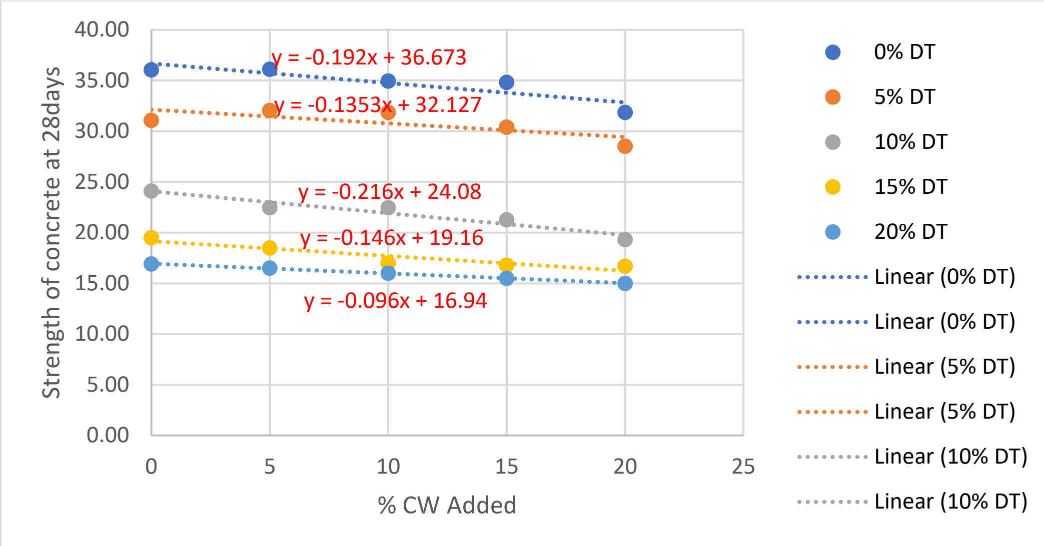

Figures 6. Regression of % ceramic waste against 28-day strength at 0%, 5%, 10%, 15%, and 20% discarded tyre

The output of the regression analysis reveals that at 0% discarded tyre, the R square obtained is 0.83800864, at 5% discarded tyre, the R square obtained is 0.902258331, for 10% discarded tyre, the R square is 0.854297, for 15%, the R square obtained is 0.73615 and for 20% discarded tyre, the R square obtained is 1. This shows a very strong relationship and hence the regression equations can be used to predict the strength of concrete for a given addition of either ceramics waste or discarded tyre.

Strength Development with Age

Table 7 presents the strength gain trend (as a percentage of 28-day strength) for the 0% discarded-tyre series across increasing ceramic waste content. All mixes reached at least 91% of their 28-day strength by 14 days, and 94-100% by 21 days, indicating that the inclusion of ceramic waste did not markedly slow early strength development relative to the control mix; if anything, mixes with ceramic waste reached a higher proportion of ultimate strength slightly earlier, consistent with a mild pozzolanic contribution from the silica- and alumina-rich ceramic waste (see Table 2).

Table 7: Strength Gain Trend of Concrete with 0% Discarded Tyre (% of 28-Day Strength)

% Ceramic Waste	7 Days	14 Days	21 Days	28 Days
0	65	91	94	100
5	65	96	100	100
10	67	97	100	100
15	67	97	100	100
20	73	98	100	100

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CONCLUSION

This study evaluated the effect of partially replacing cement with ceramic waste and coarse aggregate with discarded tyre on the fresh and hardened properties of concrete. Cubes were cast across all combinations of 0-20% ceramic waste and 0-20% discarded tyre replacement, and compressive strength was determined at 7, 14, 21, and 28 days. Regression analysis was carried out on the ultimate (28-day) strength results with respect to the percentage of ceramic waste added at each fixed level of discarded tyre content. The following observations were made:

1. For concrete made with no discarded tyre but with partial ceramic waste replacement, the relationship between percentage ceramic waste added and 28-day strength (Y, in MPa) can be expressed as $Y = -0.258x + 37.667$, where x is the percentage of ceramic waste added.
2. For concrete made with 5% discarded tyre and ceramic waste replacement ranging from 5% to 20%, the relationship is $Y = -0.2213x + 32.087$.
3. For concrete made with 10% discarded tyre and ceramic waste replacement ranging from 5% to 20%, the relationship is $Y = -0.2193x + 24.1$.
4. For concrete made with 15% discarded tyre and ceramic waste replacement ranging from 5% to 20%, the relationship is $Y = -0.0773x + 17.767$.
5. For concrete made with 20% discarded tyre and ceramic waste replacement ranging from 5% to 20%, the relationship is $Y = -0.0733x + 17.233$.
6. For cubes containing ceramic waste but no discarded tyre, ultimate strength was reached faster than in the normal (control) concrete.
7. For concrete made with no ceramic waste but with partial discarded tyre replacement, the relationship between percentage discarded tyre added and cube density (Y, in appropriate density units) can be expressed as $Y = -0.1134x + 4.19$.

Overall, compressive strength decreased consistently as the proportion of either ceramic waste or discarded tyre increased, indicating that both materials should be used at limited, optimized replacement levels rather than as full substitutes, particularly where structural performance is required.

This pattern is consistent with the wider literature on both materials: Daniel and Raju (2018) similarly found that flexural strength gains from ceramic waste powder reversed beyond a 15% cement replacement level, and Khatib and Bayomy (1999) reported non-linear compressive and flexural strength losses with increasing discarded-tyre aggregate content. Ceramic waste replacement below approximately 10%, combined with discarded tyre content below approximately 5-10%, appears most likely to preserve adequate strength while achieving the environmental and waste-reduction benefits documented for both materials (Khatib & Bayomy, 1999; Meena et al., 2022). Future work should extend the regression analysis to the full-strength dataset across all curing ages, incorporate durability and fire-resistance results from the reserved cube sets, and validate the proposed strength models against additional independent mixes.

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