Research on Engineering Structures & Materials
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Research Article

Mechanical and durability studies on different grades of concrete using cinder aggregates

Shahazadi Begum*,1,a, Shaik Yajdani 2,b

[1]*Dept. of Civil Eng., Baba Institute of Technology and Sciences Visakhapatnam, India*
[2]*Dept. of Civil Eng., Andhra University College of Engineering Visakhapatnam India*

Article Info

Article History:

Received 06 Oct 2024
Accepted 09 Apr 2025

Keywords:

M-Sand; cinder; Mechanical performance; Water absorption; Rapid chloride permeability test

Abstract

Effective waste management in the steel industry is crucial for sustainability. With rising construction costs and the depletion of natural resources, integrating industrial by-products into construction has become increasingly important. Cinder, a significant by-product of steel manufacturing, forms when molten steel separates from impurities in the furnace. This study investigates the impact of cinder on the mechanical performance of concrete, focusing on compressive strength, split tensile strength, and flexural strength after 7 and 28 days of curing, along with microstructural analysis using SEM and XRD. The research explores replacing coarse aggregate with cinder in varying proportions from 0% to 80% in 10% increments to assess its feasibility for sustainable concrete production. The test results indicate that the target compressive strength is achieved with 70%, 50%, and 40% cinder aggregate replacement in M20, M30, and M40 concrete grades, attaining 27.56 MPa, 38.67 MPa, and 49.77 MPa, respectively. Additionally, durability tests, including water absorption and RCPT, were conducted. The charge passed in M20, M30, and M40 concrete with 70%, 50%, and 40% cinder aggregate was 3550.35, 2231.22, and 1936.65 coulombs, classifying them under moderate to low permeability categories, indicating its potentiality to be used in the concrete.

1. Introduction

The rapid growth of industrialization and urbanization has accelerated the depletion of natural resources, creating significant challenges for their sustainable availability in the future. Furthermore, waste generated by manufacturing industries and construction activities consumes valuable land, reducing its utility and property value. The construction sector faces dual challenges: the scarcity of natural resources and the efficient disposal of industrial and construction waste. Adopting alternative resources to replace conventional ones is a promising step toward sustainability. Using these alternatives not only preserves natural resources for future generations but also enables the production of greener concrete. Advances in modern construction materials have facilitated the development of durable and lightweight options, significantly contributing to reducing structural weight. This progress has led to the creation of lightweight aggregate concrete (LWC). Lightweight aggregates can originate from natural rock materials, manufactured products, or industrial by-products. These aggregates are commonly used in bulk fillers for lightweight concrete, precast structural products, and road surfacing materials. Lightweight concrete is particularly advantageous for producing precast components, as its reduced weight allows for transporting larger quantities at a time. Additionally, lightweight concrete (LWC) enables the design of longer spans and more efficient bridge structures [1]. A key goal in LWC development is further reducing its density without compromising strength or increasing production costs. This is often achieved by substituting traditional aggregates with lightweight natural, agricultural, or

*Corresponding author: drshahazadibegum23@bitsvizag.com
[a]orcid.org/0009-0001-7908-5021; [b]orcid.org/0009-0008-0035-7313
DOI: http://dx.doi.org/10.17515/resm2025-475me1006rs

synthetic materials [2]. The physical properties of the coarse aggregate can significantly affect the fresh and hardened properties of the concrete [3]. This weight reduction enhances longevity and reduces the maintenance requirements of superstructures. Historically, aggregates like cinder and pumice have been employed as substitutes for conventional aggregates in lightweight concrete [4]. Yang and Huang demonstrated that the compressive strength of concrete is mainly affected by the properties and volume fraction of aggregate [5]. Lydon pointed out that for some lightweight aggregates, the compressive strength depends on the type of aggregate and increases with an increase in density [6].

Cinder, a lightweight aggregate derived as a by-product of steel and iron manufacturing, offers unique properties that influence its application in construction. Generally coarse and highly porous, with a 100% crushed face, the mineral structure of cinder contributes to its lightweight nature. This makes it ideal for various building applications, including partition wall blocks, screeding, and plastering on flat roofs. The amount of cinder waste developed in India is quite significant for use as an aggregate in concrete [7]. The high air content of aggregate provides effective sound absorption, soundproofing, and thermal insulation. With a linear coefficient of thermal expansion of approximately 3.8×10^{-6}/°C, cinder-based concrete exhibits low thermal conductivity, which makes it suitable for lightweight concrete (LWC) applications due to its reduced density, which reduces dead load, accelerating construction progress., and lowers maintenance costs [8]. Lightweight, with better insulation and high strength, lightweight concrete increases construction efficiency and reduces the foundation's strength [9]. However, developing high-strength, lightweight concrete structures is challenging, especially with increased stress and possible environmental effects that can damage and compromise the structure's integrity. Lightweight aggregates, including fly ash, are essential as bulk aggregates in various concrete applications [10], [11]. Recent studies have investigated the effect of aggregate size on the mechanical properties of lightweight concrete containing fly ash. By examining different sizes of aggregates and the composition of mineral aggregates, these studies aim to optimize the compressive and tensile strength and well strength of LWC. Proper mix design for such concretes is complex due to high water absorption and the porous nature of lightweight aggregates. Achieving the perfect combination means a lot of experimentation and tweaking. However, appropriate equations can simplify the mixing process and improve the composite design [12]. In their investigation, Hanuman Sai Gupta [8] used cinder aggregate and cinder powder to replace the coarse and fine aggregates. It was observed that the cinder powder didn't significantly impact the strength properties of concrete. However, the design target strength was attained with 40% cinder aggregates as a replacement.

Dandu Chinna Narasimhudu [13] studied lightweight concrete by replacing cement with fly ash, silica fumes, and coarse aggregate with cinder. The study concluded that 5% silica fumes and 20% fly ash with up to 60% cinder showed satisfactory results. Dr. V. Bhaskar Desai and Mr. A. Sathyam [14] studied the behavior of lightweight concrete by replacing natural aggregate with cinder aggregate in proportions such as 0,25,50,75 and 100 by volume. A total of 105 specimens were cast to evaluate their performance. It was concluded that an increase reduced concrete's mechanical behavior in the cinder aggregate proportion. However, the target mean strength of concrete was achieved with 75% cinder aggregate content.

N. Sivalinga Rao et al. [15] demonstrated the importance of trial mixes in lightweight concrete, highlighting the lack of precise water absorption and moisture content data. Their research indicated that replacing 60% of regular aggregate with cinder by volume and substituting 10% of the cement weight with silica fume could achieve the desired strength for M20 concrete. They found that using 40% cinder and 60% natural aggregates with 10% silica fume replacement for cement was the optimal combination. They also observed a slight increase in strength and other properties with extended curing periods. The unit weight of the cinder concrete ranged from 1980 kg/m^3 to 2000 kg/m^3 depending on the amount of cinder used, although the density decreased after prolonged curing.

Rathish Kumar P et al. [16] assessed concrete's strength and Sorptivity characteristics using cinder-based lightweight aggregates. They started by optimizing the aggregate size and evaluating the mechanical properties of medium-grade concretes with different aggregate sizes. Their findings revealed that the best mechanical properties for 20 MPa lightweight concrete were achieved with 12.5 mm aggregates and a 30% fly ash replacement. Conversely, for 30 MPa concrete, 10 mm aggregates with a 30% fly ash replacement improved the properties.

Sanjana et al. [17] studied the performance of concrete using cinders and fly ash granules as a substitute for coarse and fine aggregates on M20-grade concrete. It was observed that the performance of concrete in compression and tension was reduced by 35% and 15% with 100% cinder aggregate. They also concluded that cinder can be used as an aggregate replacement for up to 60% of the conventional aggregate. H. Z. Cui et al. [18] investigated the impact of lightweight aggregates (LWA) on the mechanical properties and brittleness of lightweight aggregate concrete (LWAC). The research introduces a new "Shape Index" to quantify aggregate shape characteristics and evaluates its influence on concrete performance. Experimental results show that LWA volume fraction significantly affects compressive strength and elastic modulus, with higher LWA content leading to increased brittleness. LWAC is more brittle than normal-weight concrete (NWC) for similar strengths. Additionally, fracture energy analysis confirms that NWC exhibits better toughness. The findings emphasize the importance of LWA properties in LWAC design.

1.1 Research Significance

Incorporating cinder aggregates in concrete holds significant research value regarding sustainability, economic benefits, and structural performance. This study contributes to the growing demand for eco-friendly construction materials by utilizing cinder, a by-product of steel manufacturing, as a partial replacement for natural coarse aggregates. The present study focused on using the cinder aggregates and manufactured sand in combination in which the proportions of the cinder aggregates varied from 0-80% with 10% intervals in different grades of concrete, such as M20, M30, and M40.

2. Materials

2.1 Binding Material

The entire research utilized Ordinary Portland Cement of 43 grade as a binding material manufactured by Sagar cement, conforming to IS: 8112-2013[19], having a specific gravity of 3.13 with 2% fineness.

2.2 Fine Aggregate

Manufactured sand (M-Sand) was fully utilized to replace natural river sand as a fine aggregate, classified under Zone-II as per IS: 383-2016 [20]. The specific gravity was 2.66, and the water absorption rate was 1.32%. The grading curve for the m-sand is illustrated in (Fig. 1).

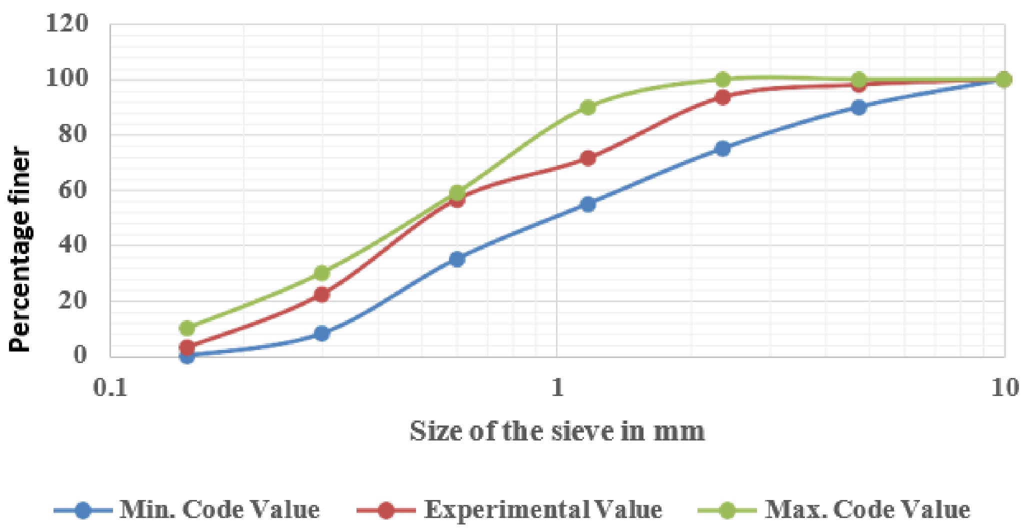

Fig. 1. Grading curve of M-Sand

2.3 Natural Coarse Aggregates and Cinders

The natural coarse aggregates (NCA) used in the study were obtained from the local area and had nominal sizes of 20 mm and 10 mm. Cinder partially replaced the coarse aggregates, as seen in (Fig. 2). The EDAX analysis of the cinder aggregate is presented in (Fig. 3) and Table 1. The cinders used were derived from small, porous volcanic rocks and are commonly utilized in lightweight concrete applications due to their lightweight and porous nature. The high porosity of cinder aggregates contributes to reduced density, and using high percentages of cinder aggregate could amplify the challenges related to strength reduction. Cinder aggregate have low density, high porosity, availability and cost- effectiveness, compatibility with cement, and sustainability. The specific gravity of the cinder aggregate was measured to be 1.95, and the grading curve is depicted in (Fig. 4).

Fig. 2. Cinder aggregate

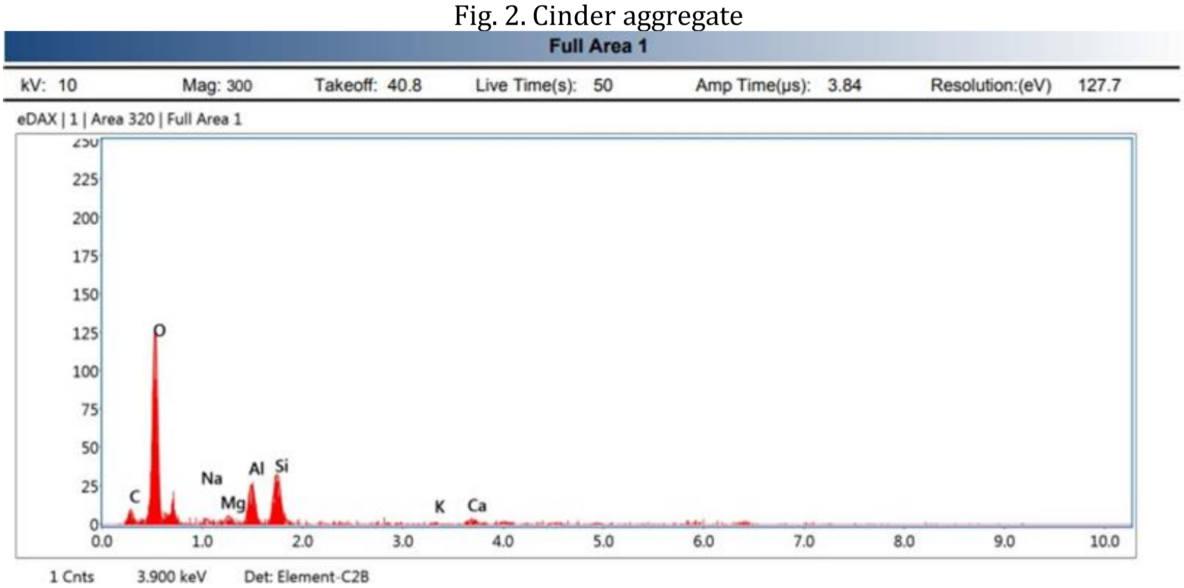

Fig. 3. EDAX analysis of cinder aggregate

The EDAX analysis spectrum shown in the above figure provides a qualitative and quantitative analysis of the elemental composition of the cinder aggregate used in the concrete mix. The peaks represent different elements in the cinder, such as Si, Al, Ca, etc., contributing to its mineralogical properties—the high silica and alumina content support pozzolanic activity, improving the concrete matrix's strength and density. Calcium content enhances hydration, contributing to better bonding in the interfacial transition zone (ITZ). The porous structure and lightweight oxides (e.g., silica and alumina) ensure a significant reduction in density, which is crucial for lightweight concrete applications. Stable oxides such as Fe_2O_3, SiO_2, and Al_2O_3 enhance resistance to chemical attacks and environmental degradation. The high oxygen and silica content correlate with cinder aggregates' excellent thermal insulation properties.

Table 1. EDAX analysis of cinder aggregate

Element	C	O	Na	Mg	Al	Si	K	Ca	Ti
Weight (%)	0.32	47.49	2.16	2.47	11.95	16.69	3.05	8.52	7.35

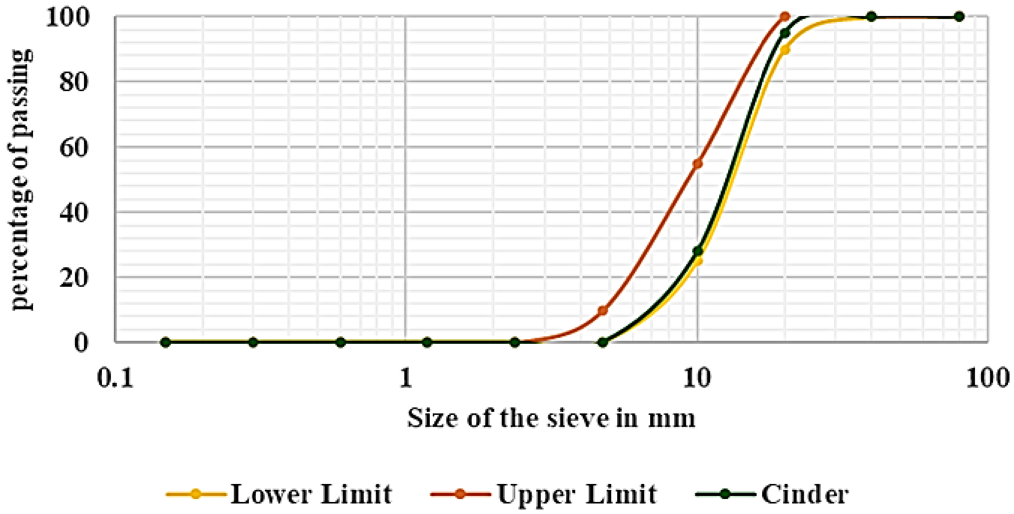

Fig. 4. Grading curve of coarse aggregate

3. Mix Proportion and Designation

The mix design was conducted according to the guidelines specified in IS:10262-2019 [21]. The target strengths were 26.6 MPa, 38.25 MPa, and 48.25 MPa for M20, M30 and M40 respectively. Tables 2 and 3 provide the details of mix notations and proportions, while Table 4 outlines the number of specimens cast. In total, 22 different mixes were evaluated in this study. Among these, three were conventional mixtures using 100% Natural Coarse Aggregate (NCA). NCA was partially replaced with a cinder in the remaining mixes, with replacement levels of 0% to 80% for M20, 0% to 60% for M30, and 0% to 50% for M40 concrete grades.

Table 2. Notations of the mixes

Series	Notation	Abbreviation
M20	M20C0	M20 grade concrete with 0% cinder aggregate
	M20C10	M20 grade concrete with 10% cinder aggregate
	M20C20	M20 grade concrete with 20% cinder aggregate
	M20C30	M20 grade concrete with 30% cinder aggregate
	M20C40	M20 grade concrete with 40% cinder aggregate
	M20C50	M20 grade concrete with 50% cinder aggregate
	M20C60	M20 grade concrete with 60% cinder aggregate
	M20C70	M20 grade concrete with 70% cinder aggregate
	M20C80	M20 grade concrete with 80% cinder aggregate
M30	M30C0	M30 grade concrete with 0% cinder aggregate
	M30C10	M30 grade concrete with 10% cinder aggregate
	M30C20	M30 grade concrete with 20% cinder aggregate
	M30C30	M30 grade concrete with 30% cinder aggregate
	M30C40	M30 grade concrete with 40% cinder aggregate
	M30C50	M30 grade concrete with 50% cinder aggregate
	M30C60	M30 grade concrete with 60% cinder aggregate
M40	M40C0	M40 grade concrete with 0% cinder aggregate
	M40C10	M40 grade concrete with 10% cinder aggregate
	M40C20	M40 grade concrete with 20% cinder aggregate
	M40C30	M40 grade concrete with 30% cinder aggregate
	M40C40	M40 grade concrete with 40% cinder aggregate
	M40C50	M40 grade concrete with 50% cinder aggregate

Table 3. Proportions of the mixes for 1m3 of concrete

Series	Mix Id	Cement (kg/m^3)	Water	Fine aggregate (kg/m^3)	20 mm aggregate (kg/m^3)	10 mm aggregate (kg/m^3)	Cinder aggregate (kg/m^3)
M20	M20C0	320	144	740.12	793.07	528.720	0
	M20C10	320	144	740.12	713.767	475.844	132.179
	M20C20	320	144	740.12	634.459	422.973	264.358
	M20C30	320	144	740.12	555.152	370.101	396.537
	M20C40	320	144	740.12	475.844	317.230	528.716
	M20C50	320	144	740.12	396.480	264.358	660.838
	M20C60	320	144	740.12	317.230	211.486	793.074
	M20C70	320	144	740.12	237.922	158.615	925.253
	M20C80	320	144	740.12	158.615	105.743	1057.43
M30	M30C0	400	176	679.44	734.340	489.550	0
	M30C10	400	176	679.44	694.566	440.595	122.389
	M30C20	400	176	679.44	587.472	391.640	244.778
	M30C30	400	176	679.44	514.038	342.685	367.167
	M30C40	400	176	679.44	440.604	293.730	489.556
	M30C50	400	176	679.44	367.167	244.778	611.945
	M30C60	400	176	679.44	293.736	195.820	734.334
M40	M40C0	435	166	655.58	746.340	497.560	0
	M40C10	435	166	655.58	671.706	447.804	124.390
	M40C20	435	166	655.58	597.072	398.048	248.780
	M40C30	435	166	655.58	522.438	348.292	373.170
	M40C40	435	166	655.58	447.804	298.536	497.560
	M40C50	435	166	655.58	373.170	248.780	621.950

Table 4. Details of the specimen cast

Property	Shape of the specimen	Size of the specimen (mm)	Code	Testing age (days)	Number of specimens M20	M30	M40
Slump	-	-	IS:1199-2018(PartII)	Fresh concrete	-	-	-
Compressive strength	Cube	150x150x150	IS: 516-1999	7,28	54	42	36
Split tensile strength	Cylinder	150 x 300	IS: 5816-1999	7,28	54	42	36
Flexural strength	Prism	500 x 100 x100	IS: 516-1999	7,28	54	42	36
Density	Cube	150 x 150 x150	IS: 6441-1997 (Part– I)	28	Performed on the cubes used for finding compressive strength		
Water absorption	Cube	150 x 150 x150	IS: 6441-1997 (Part-II)	28	6	6	6
RCPT	Cylinder	100 mm Ø with 50 mm thickness	ASTM C 1202-12	28	6	6	6
Sorptivity	Disc	100 mm Ø with 50 mm thickness	ASTM C 1585-04	28	6	6	6

4. Results and Discussion

4.1 Workability

The workability of concrete refers to how easily freshly mixed concrete can be placed, compacted, and finished without the components separating. It measures how well concrete can be handled and worked into the desired shape and location while maintaining uniformity and consistency. The current study evaluates the workability of the concrete by performing a slump cone test on all grades of concrete as per IS: 1199-2018 [22]. In all the concrete grades, it has been observed that when the cinder's content increased, a slump reduction was observed due to the cinder's rough surface texture and highly porous nature. The variation in the slump of the concrete is illustrated in (Fig. 5).

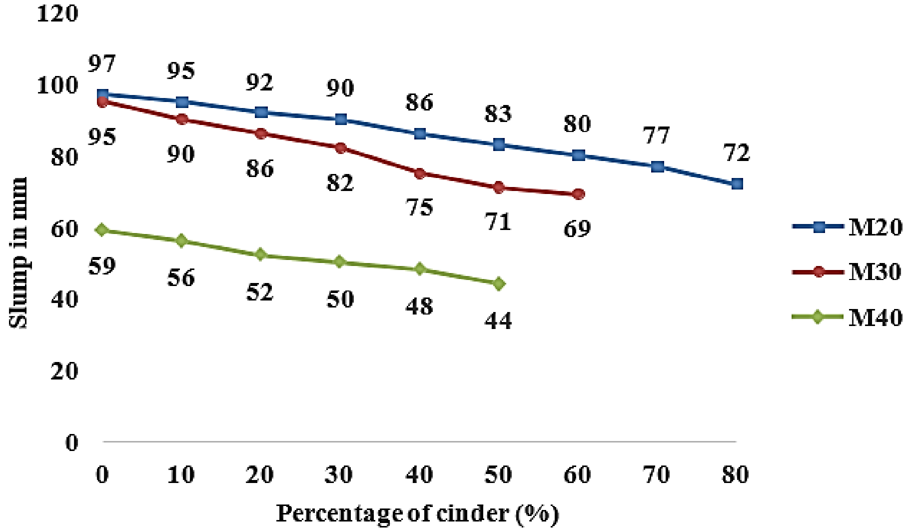

Fig. 5. Variation of slump in concrete

4.2 Density

The concrete density was examined using cube specimens for all mixes after completing the curing period as per the Indian code IS: 6441-1997 [23]. The density of concrete exhibited a declining nature with an increase in the level of cinder aggregate. Similar behavior in decreasing density is observed in work carried out by Chinmay Sahoo et al. [24]. This decrease is likely due to the lightweight nature of the cinder aggregates. Specifically, the density decreased from 2675 kg/m^3 to 2059 kg/m^3 for M20, from 2527 kg/m^3 to 2068 kg/m^3 for M30, and from 2705 kg/m^3 to 2092 kg/m^3 for M40 grades of concrete. The variation in concrete density is shown in (Fig. 6).

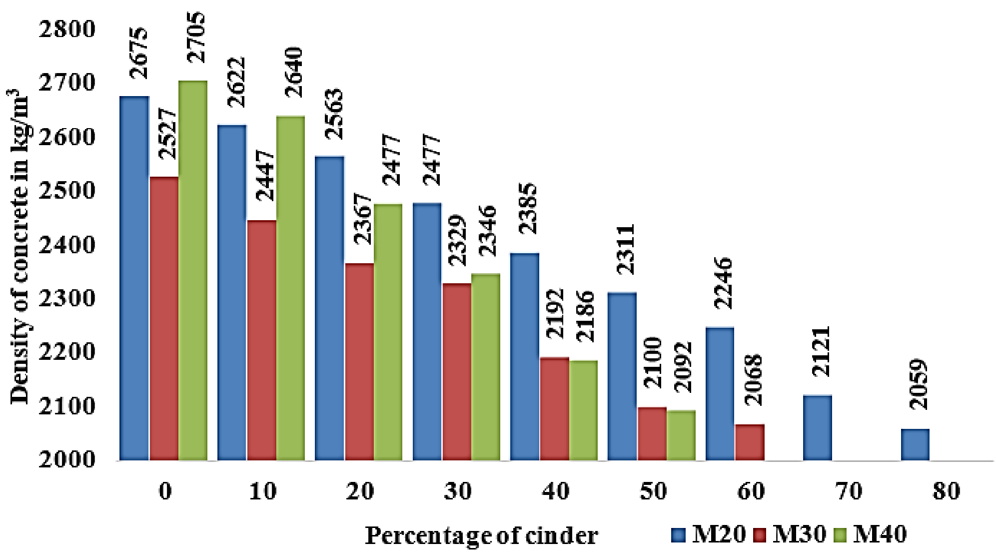

Fig. 6. Variation of the density of concrete

4.3 Compressive Strength

For all the mixes specified in Table 3, the compression test is performed after completing the 7 and 28-day curing period as per IS: 516-1999 [25]. Table 5 presents the mechanical performance of concrete for all mixes. From Table 5, the compressive strength decreased as the replacement level of cinder aggregate increased. A similar declining pattern of the test outcomes in compressive strength is observed in the work carried out by Anil Kumar Agarwal et al. [26].

Table 5. Mechanical performance results on M20, M30 and M40 concrete grades

Mix Id	Compressive strength(N/mm^2)			Split tensile strength (N/mm^2)			Flexural strength (N/mm^2)		
	7 days	28 days	% of decrease	7 days	28 days	% of decrease	7 days	28 days	% of decrease
M20C0	24.44	31.11	0	2.54	3.11	0	5.12	5.21	0
M20C10	23.56	30.67	1.41	2.47	2.97	4.50	5.07	5.14	1.34
M20C20	22.67	30.36	2.41	2.38	2.94	5.47	4.96	5.07	2.69
M20C30	21.78	30	3.57	2.33	2.87	7.72	4.85	4.99	4.22
M20C40	20	29.78	4.28	2.26	2.83	9.00	4.7	4.77	8.45
M20C50	16.89	28.89	7.14	2.12	2.66	14.47	4.47	4.63	11.13
M20C60	16	28	10.00	2.06	2.63	15.43	4.19	4.41	15.36
M20C70	15.56	27.56	11.41	2.04	2.54	18.33	4.04	4.26	18.23
M20C80	14.67	24.89	19.99	1.87	2.47	20.58	3.45	3.49	33.01
M30C0	23.56	42.67	0	2.54	4.1	0	7.56	7.8	0
M30C10	22.67	40.89	4.17	2.47	3.9	4.88	7.1	7.4	5.13
M30C20	22.22	40	6.26	2.26	3.88	5.37	6.75	7.1	8.97
M30C30	21.78	39.56	7.29	2.12	3.68	10.24	6.62	6.7	14.10
M30C40	20.89	39.11	8.34	2.06	3.58	12.68	6.57	6.3	19.23
M30C50	20.44	38.67	9.37	2.04	3.47	15.37	6.38	6	23.08
M30C60	18.67	36.44	14.60	1.87	3.22	21.46	5.67	5.9	24.36
M40C0	51.56	54.67	0	3.32	3.58	0	7.75	8.73	0
M40C10	51.48	53.68	1.81	3.25	3.4	5.03	7.16	8.25	5.50
M40C20	43.55	51.56	5.69	3.12	3.25	9.22	7	7.6	12.94
M40C30	42.67	50.67	7.32	2.97	3.12	12.85	6.94	7.43	14.89
M40C40	40.87	49.77	8.96	2.83	3.11	13.13	6.87	6.67	23.60
M40C50	36.44	44.87	17.93	2.63	2.93	18.16	5.93	6.13	29.78

Due to the porous nature of the aggregate, it increases porosity, and due to the lower density of cinder aggregate, it produces concrete having lower density, which correlates with lower compressive strength because the material has more voids and less solid mass to resist compressive forces. The compressive strength of mix M20C0 after 28 days was found to be 31.11 MPa. However, for M20C80, which contains 80% cinder aggregates, the compressive strength decreased to 24.89 MPa. The decrease percentage was 19.99% for concrete, with 80% cinder aggregates in M20 concrete. The rate of decrease in strength is shown in Figure 7 for M20 concrete. The compressive strength of mix M30C0 after 28 days was found to be 42.67 MPa. However, for M30C60, which contains 60% cinder aggregates, the compressive strength decreased to 36.44 MPa. The decrease percentage was 14.60% for concrete, with 60% cinder aggregates in M30 concrete. The rate of decrease in strength is shown in Figure 8 for M30 concrete. The compressive strength of mix M40C0 after 28 days was found to be 51.56 MPa. However, for M40C50, which contains 50% cinder aggregates, the compressive strength decreased to 44.87 MPa. The decrease percentage was 17.93% for concrete, with 50% cinder aggregates in M40 concrete. The rate of decrease in strength is shown in Figure 9 for M40 concrete. However, it must be noted that the target strength can be achieved even with a 70% replacement of cinder aggregates in M20-grade concrete. Regarding the M30 and M40 grades of concrete, the target strength can be achieved even with 50% and 40% replacement levels of cinder aggregates, respectively.

4.4 Split Tensile Strength

As concrete is weaker in tension than compressive strength, this test helps understand how concrete will behave under tensile stresses. Knowledge of tensile strength helps predict concrete cracking behavior. The specimens are tested after 7 and 28 days of curing, following the procedure detailed in IS-5816-1999[27]. Like the compressive strength, the split tensile strength decreased as the cinder aggregate replacement increased. The test results are mentioned in Table 5. The strength of the M20C0 mix was 3.11 MPa after 28 days. However, for M20C80, it decreased to 2.47 MPa, marking a 20.58% reduction in strength with 80% cinder aggregates. This decrease is depicted in Figure 7. In the M30C0 mix, the strength was 4.1 MPa after 28. M30C60's strength dropped to 3.22 MPa, resulting in a 21.46% decrease with 60% cinder aggregates. Figure 8 illustrates this reduction. After 28 days, the strength of the M40C0 mix was 3.58 MPa. This strength fell to 2.93 MPa for M40C50, a decrease of 18.16% with 50% cinder aggregates. The reduction is shown in Figure 9. The decrease in concrete performance is attributed to the characteristics of cinder aggregate, which is highly porous. This porosity increases micro-cracking within the concrete matrix when under tensile stress. The split tensile strength of concrete also relies on the strength of the aggregates. Given that cinder aggregates are weaker than conventional aggregates, the split tensile strength of cinder aggregate concrete may be lower.

4.5 Flexural Strength

The flexural strength of concrete significantly affects its structural performance. The flexural behavior is evaluated after 7 and 28 days of curing, following the guidelines of IS- 516-1959 [25]. The test results are listed in Table 5. The flexural strength of the M20C0 mix was 5.21 MPa after 28 days of curing. However, M20C80 decreased to 3.49 MPa, indicating a 33.01% reduction in strength with 80% cinder aggregates. This decrease can be seen in (Fig. 7). In the M30C0 mix, the flexural strength was 7.8 MPa after 28 days. M30C60's strength dropped to 5.9 MPa, resulting in a 24.36% decrease with 60% cinder aggregates. (Fig. 8) illustrates this reduction. After 28 days, the flexural strength of the M40C0 mix was 8.73 MPa. This strength fell to 6.13 MPa for M40C50, a decrease of 29.78% with 50% cinder aggregates. The reduction can be seen in (Fig. 9). The negative performance is due to the light weight of the cinder, which produces lightweight concrete that exhibits different stress distribution and deformation characteristics under load.

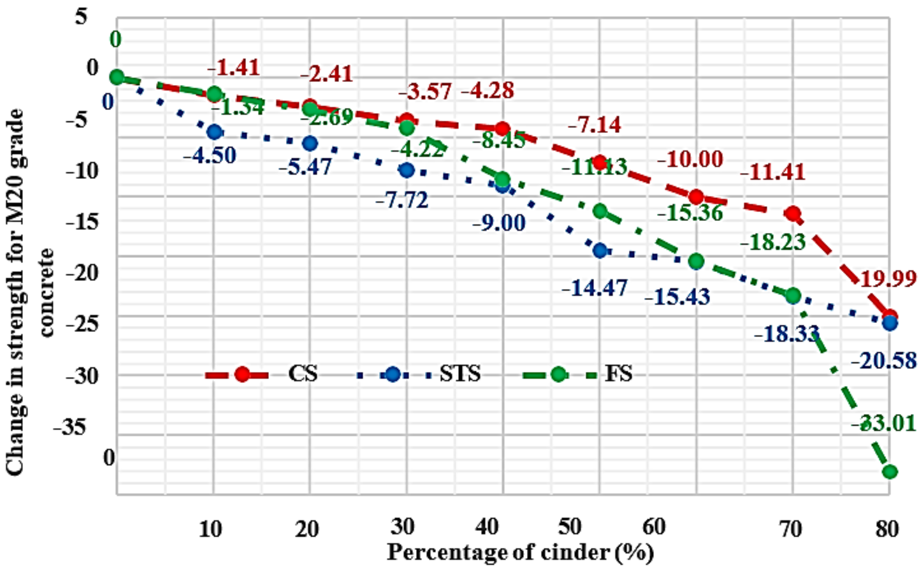

Fig. 7. Change in strength for M20 grade concrete

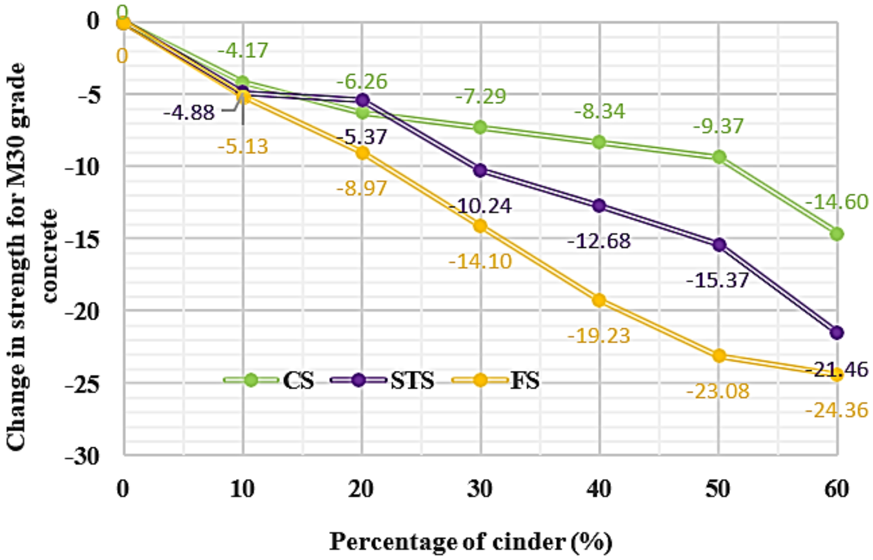

Fig. 8. Change in strength for M30 grade concrete

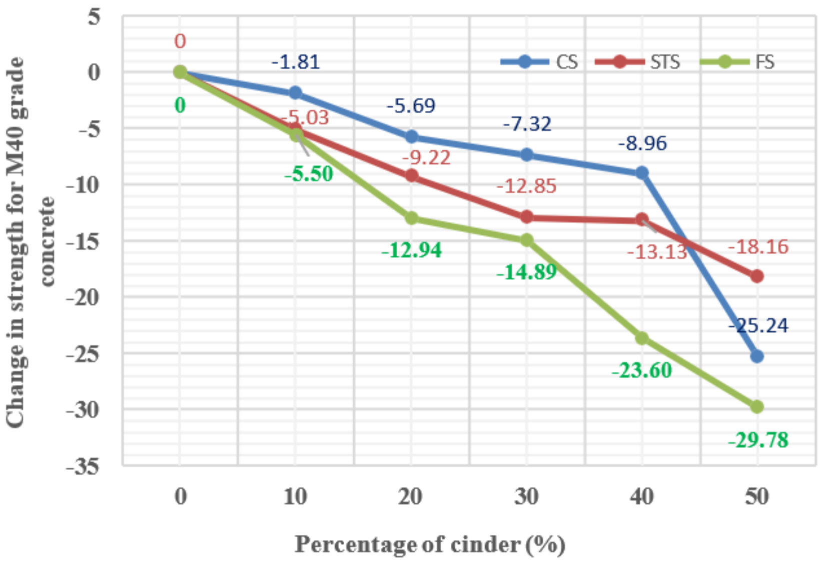

Fig. 9. Change in strength for M40 grade concrete

4.6. Correlation Among the Mechanical Properties of Concrete

The R^2 values were found to be 0.8809, 0.8685, and 0.8801, which indicates a strong correlation for the M20, M30, and M40 grades of concrete, respectively, between the compressive strength and hardened density of concrete, and is illustrated in (Fig. 10). The R^2 values were 0.8664, 0.9481, and 0.8846 for the M20, M30, and M40 concrete grades, suggesting a strong correlation between compressive and split tensile strength, as shown in (Fig. 11). For the relationship between compressive strength and flexural strength, shown in (Fig. 12), the R^2 values were found to be 0.9925 for M20 concrete, 0.9163 for M30 concrete, and 0.8075 for M40 concrete, indicating a robust correlation.

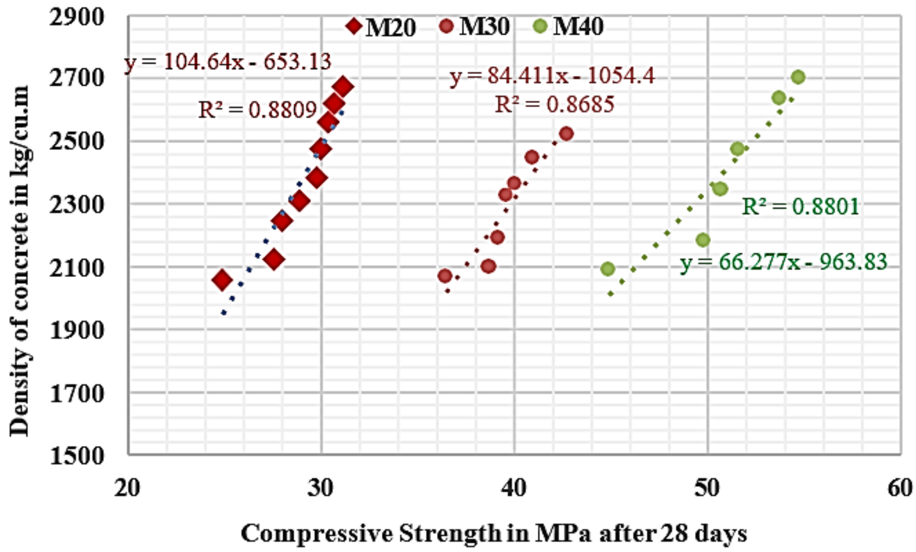

Fig. 10. Linear regression between compressive strength and density on all mixes

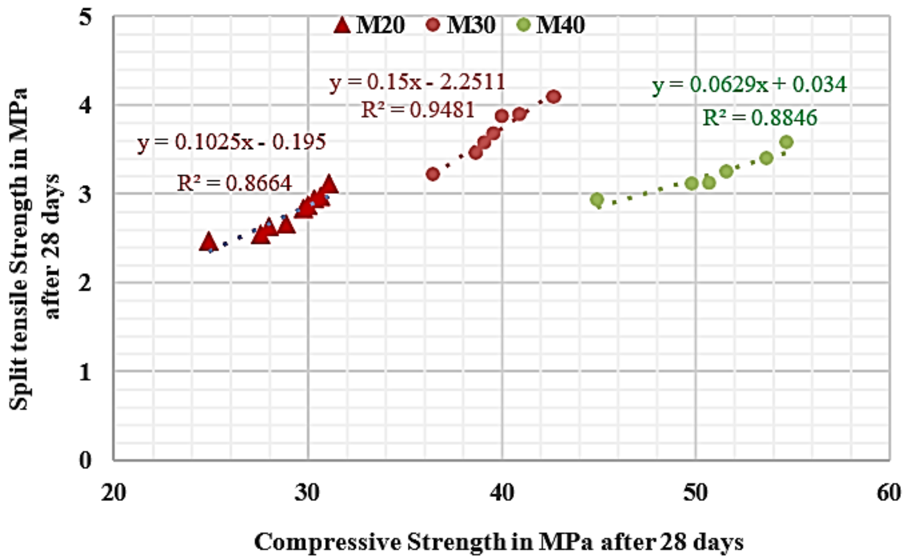

Fig. 11. Linear regression between compressive strength and split tensile strength on all mixes

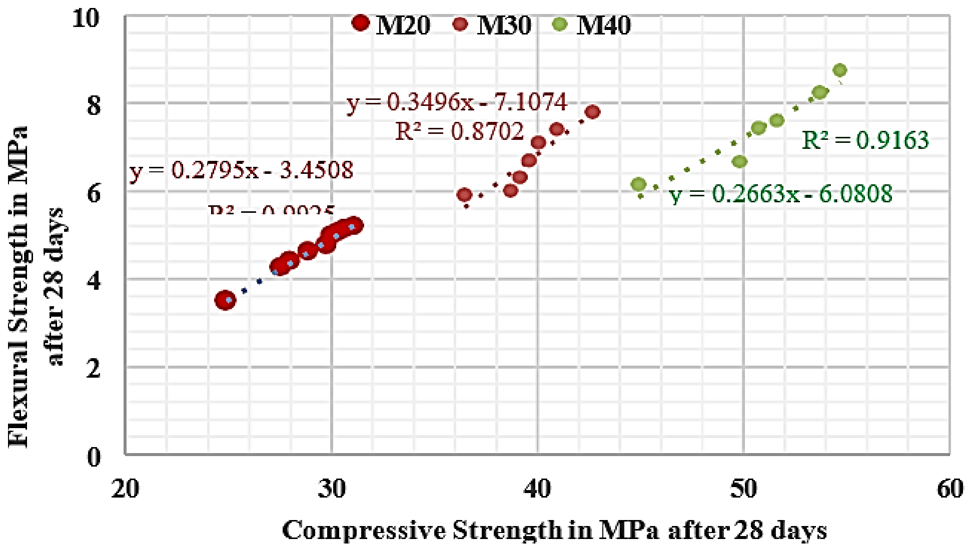

Fig. 12. Linear regression between compressive strength and flexural strength on all mixes

4.7 Water Absorption

By predicting the potential performance and long-term maintenance needs of concrete structures, the water absorption test helps ensure their longevity and reliability. This test is conducted on 150 mm cube specimens by ASTM C-642 [28]. It is applied to both conventional mixes and those with the maximum replacement of cinder aggregate.

Fig. 13. Specimens subjected to water curing

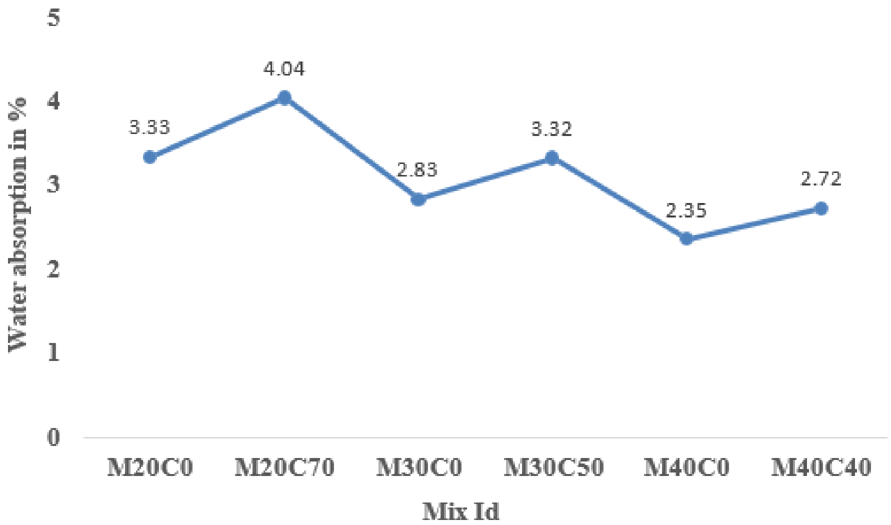

Fig. 14. Water absorption

The samples tested have undergone 28 days of curing. (Fig. 13). shows the specimens immersed in water required for water absorption. (Fig. 14). shows that water absorption decreased with higher concrete grades and increased with higher levels of cinder aggregate. Cinder aggregates typically have a higher degree of porosity and high-water absorption than traditional aggregates, which results in more water being absorbed. The variation in the test results is presented in (Fig. 14).

4.8 Rapid Chloride Penetration Test

The Rapid Chloride Permeability Test (RCPT) is a crucial durability test used to assess the resistance of concrete to the penetration of chloride ions.

Table 6. Test results of RCPT

Mix Id	Charge passed in coulombs	Permeability	ASTM C-642
M20C0	1868.85	Low	High permeability: > 4000 coulombs Moderate permeability: 2000 to 4000 coulombs Low permeability: 1000 to 2000 coulombs Very low permeability: 100 to 1000 coulombs Negligible permeability: < 100 coulombs
M20C70	3550.35	Moderate	
M30C0	1664.85	Low	
M30C50	2231.22	Moderate	
M40C0	1500.33	Low	
M40C40	1936.65	Low	

The test involves cylindrical specimens in line with ASTM C-642 [28]. Table 6 shows that the charge passed increased with an increase in the replacement level of cinder aggregate. The high porosity of the cinder aggregate allows a large amount of chloride ions to pass through. The weaker interfacial transition zone between the cinder aggregates and the cement paste also creates a more porous pathway for chloride ions. For reference, the test setup is illustrated in (Fig. 15), and the outcomes are presented in Table 6.

Fig. 15. RCPT test setup

5. Conclusions

- Replacing natural river sand with manufactured sand can help reduce environmental impacts, preserving natural resources and the economy.
- The use of cinder aggregates not only helps conserve natural resources but also supports the broader goals of sustainable construction.
- The test outcomes of the workability by slump have shown that the ease of work with the cinder aggregates reduced with an increase in the proportion of the cinder aggregate in concrete in all the grades.
- The test results indicated that higher-grade concrete exhibited greater density values. However, as the proportion of cinder aggregate increased, the overall density of the concrete showed a decreasing trend.
- The strength of concrete in compression is 27.56 MPa, 38.67 MPa, and 49.77 MPa for M20C70, M30C50, and M40C40 mixes, which is more than the target strength.
- From the mechanical performance outcomes, it can be concluded that the lower the grade of concrete, the higher the replacement level of cinder aggregate can be used.
- The experimental results indicate that in M20 grade concrete, the desired strength is attained even when 70% of natural coarse aggregates are substituted with cinder aggregates. For M30 and M40 grades of concrete, the corresponding percentages are 50% and 40%.
- At higher dosages of cinder aggregates particularly in the higher grades of concrete, the performance of concrete exhibited a poorer performance.
- The regression analysis shows a strong correlation between compressive strength and hardened density, split tensile strength, and flexural strength.
- The results of the RCPT test indicate that as the concrete grade increases, the charge passed in coulombs decreases, showing high resistance to chloride ion penetration.
- The test results for water absorption show that concrete with cinder aggregates has increased water absorption due to the porous nature of the aggregate. The more cinder aggregate present, the higher the water absorption.
- As cinder aggregates have low specific gravity, they can be used for lightweight concrete applications.

- Cinder aggregates may be more suitable for applications where high strength and low permeability are less critical, such as in non-structural elements or buildings in low-exposure environments.

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