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Enhancing high-performance concrete properties through partial replacement of fine aggregate with crusher run dust: A comprehensive experimental investigation

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Abstract

This experiment explores the potential of crusher-run dust, a waste product from crusher plants, to enhance high-performance concrete. It investigates the effects of the partial replacement of sand with crusher-run dust in various ratios. The replacement of fine aggregate with crusher run dust has been considered for M50 grade design mix concrete with 0%, 15%, 30%, 45%, and 60%, and the change in characteristics has been considered. A superplasticizer was utilized to keep the workability between 76mm and 85mm. In this experimental investigation, the mechanical properties of concrete, such as compressive strength, flexural strength, split tensile strength, and porosity, have been examined. The results show that the characteristics of concrete improved, with the best results observed when using a 30% concentration of crusher-run dust in concrete, suggesting potential benefits for the construction industry.

Keywords
Concrete; Crusher run dust; Fine Aggregate; Strength.

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1 Introduction

Building is its foundation, and concrete is its primary component in civil engineering. The use of concrete in construction is generally acknowledged. As the fundamental component of today's technologically advanced construction industry, concrete plays a crucial role [1]. Every part of the world uses a significant amount of concrete. An essential component of concrete is fine aggregate. Because there is a rising need for concrete for the construction of infrastructure, there is a need for an alternative material that can meet the demand for fine aggregate in concrete [2].

Industries today produce a significant amount of garbage, posing health risks. Another critical issue with this garbage is disposal. This trash can be successfully used in the production of concrete [3]. Crusher-run dust, another waste product produced by crushing facilities, can be used successfully in concrete. Based on the previous study, it was discovered that crusher-run dust's qualities are somewhat comparable to those of fine aggregate and that it can be used in place of fine aggregate [4].

This study investigates the use of stone dust in place of natural sand in concrete. Tests on the physical and mechanical characteristics of stone dust revealed enhanced compressive and flexural strengths with 40–60% replacement of stone dust, providing a cost-effective substitute for depleting natural sand resources [5]. Due to excessive sand dredging, the building industry's reliance on concrete, which utilizes a lot of sand, has raised environmental issues. To replace sand in concrete, this study investigates the use of crushed limestone dust, showing favorable or equivalent results in a range of mechanical and physical qualities [6]. Cementitious composites are widely utilized yet with high CO2 emissions, looking for environmentally suitable substitutes such as industrial wastes (Fly Ash, Silica Fume, GGBS). This study evaluates their durability, strength, and eco-friendliness while also substituting granite quarry dust for river sand [7]. This study investigates using non-biodegradable quarry dust as a sustainable substitute for river sand in concrete. Over seven, fourteen, and twenty-eight days, tests with different replacement percentages (0%, 25%, 50%, and 75%) showed enhanced flexural strength compared to conventional concrete [8]. Due to strong demand and limited availability in top nations, quarry dust is being investigated to replace river sand in M50-grade concrete. According to research, adding quarry dust (0–100%) in place of river sand improves the compressive and tensile strength of concrete [9]. This study explores replacing river sand with Eco-Sand (a by-product of cement manufacturing) in concrete construction due to the increasing demand and cost of natural sand. Results suggest 18% as the optimal replacement percentage, aiming to reduce pollution and promote environmental friendliness [10]. The study investigates the use of quarry dust as a secondary by-product to improve mechanical qualities in self-compacting concrete (SCC). It looks into replacing different amounts of river sand (0%-100%) with quarry dust as well as the addition of alcofine and silica fume. Increased C-S-H concentration and decreased pores are found via microstructure analysis. The strongest result is obtained when 100% of the QD is replaced. This method not only enhances the characteristics of concrete but also minimizes quarry waste [11]. Previous studies have shown that crusher-run dust, a waste product, can partially replace sand in construction projects.

In the concrete production industry, tackling the environmental and economic obstacles caused by the reduced availability of natural sand resources is essential. Recent research emphasizes the possibility of utilizing industrial waste as an eco-friendly option. When stone dust is used to substitute 40-60% of natural sand in concrete, it can improve compressive and flexural strengths, providing a cost-effective option. Crushed limestone dust also shows favorable mechanical characteristics, making it a sustainable alternative. Additionally, studies on granite quarry dust and Eco-Sand have revealed substantial enhancements in the strength and durability of concrete. Adding quarry dust into concrete, especially in high-demand areas, enhances its compressive and tensile strengths. Moreover, using crusher-run dust to partially replace sand has yielded positive outcomes, supporting the sector's efforts to promote sustainability and decrease CO2 emissions. This study aims to investigate these options further, concentrating on how they affect high-performance concrete characteristics.

This study focuses on the large amounts of waste generated when extracting and treating rocks at crusher plants, specifically focusing on crusher-run dust. The study aims to examine the impact of substituting some of the fine aggregates with crusher-run dust on the characteristics of high-performance concrete. This study seeks to identify the best replacement ratio that improves the mechanical characteristics of concrete, including compressive strength, flexural strength, split tensile strength, and porosity. By examining these elements, the research aims to offer an affordable and enduring substitute for natural sand, ultimately decreasing garbage and ecological footprint in the building sector.

2 Research Significance

The importance of this research lies in its investigation of utilizing crusher-run dust, a by-product of crusher plants, as a substitute for fine aggregate in high-performance concrete. This method solves the urgent problem of decreasing natural sand and the adverse environmental effects of sand extraction by presenting a sustainable and affordable alternative material. The unique feature of the research is its thorough investigation of different substitution rates of crusher run dust in M50 grade concrete, offering a full comprehension of its potential advantages. By using this waste material, the study not only encourages effective waste disposal but also aids in the progress of eco-friendly construction methods, helping to further sustainable solutions in civil engineering.

3 Materials

3.1 Cement and Aggregate

Portland Pozzolana cement was utilized in this study. According to IS 1489-1:1991 [12], a binding agent's specific gravity test revealed that it was 3.12. In this study, fine aggregates with a size smaller than 4.75mm were used that had been carefully graded. The fine aggregate's specific gravity was determined to be 2.727, and its fineness modulus was found to be 2.22. The coarse aggregate's maximum size was 20 mm, and its specific gravity was 2.71. Aggregate testing was done following IS 383:1970 [13] and IS 2386:1963. Tables 1 and 2 display Portland pozzolana cement's physical and chemical properties. Similarly, table 3 shows the properties of fine and coarse aggregate. Figure 1 illustrates the fine and coarse aggregate's particle size distribution (PSD) curve.

Table 1: Physical properties of Portland Pozzolana cement

Physical Requirements	Units	Value
Specific Gravity	-	3.12
Specific surface area	m^2/kg	295
Average particle size	μm	27.6
Soundness	mm	3.42
Initial Setting Time	Min	146
Final Setting Time	Min	281
28-Day Compression Strength	33Mpa	53 Mpa

Table 2: Chemical properties of Portland Pozzolana cement

Chemical Composition	Test Value (%)
Loss on Ignition	1.46
Insoluble Residue	7.23
MgO	4.76
SO_3	3.11
Cl	0.03
CaO	53.7
SiO_2	23.13
Al_2O_3	6.27
Fe_2O_3	1.89
K_2O	0.95
Free Lime	1.92

Table 3: Properties of fine and coarse aggregate

Properties	Units	Fine Aggregate	Coarse Aggregate
Specific Gravity	-	2.59	2.72
Bulk Density (Loose)	g/cm^3	1.3	1.33
Bulk Density (Compacted)	g/cm^3	1.45	1.49
Fineness Modulus	-	2.86	6.31
Crushing Strength	-	-	19.89%
Water Absorption	-	1.21%	0.44%
Impact Value	-	-	16.70%

3.2 Crusher run dust

his study used waste material called crusher-run dust from a crusher factory in Fewa Siltan Dam, Kaski, Nepal. Zone III crusher-run dust was employed with a specific gravity and fineness modulus of 2.69 and 2.72. According to IS 383:1970, a sieve analysis was conducted [13]. Figure 2 below shows the PSD of crusher run dust.

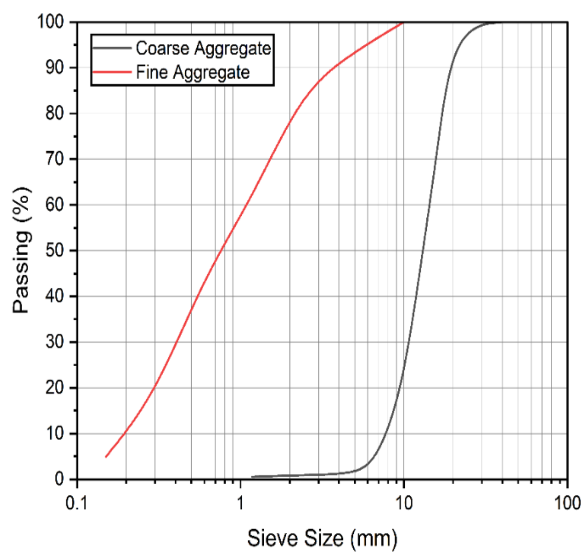

Figure 1: PSD of fine and coarse aggregate.

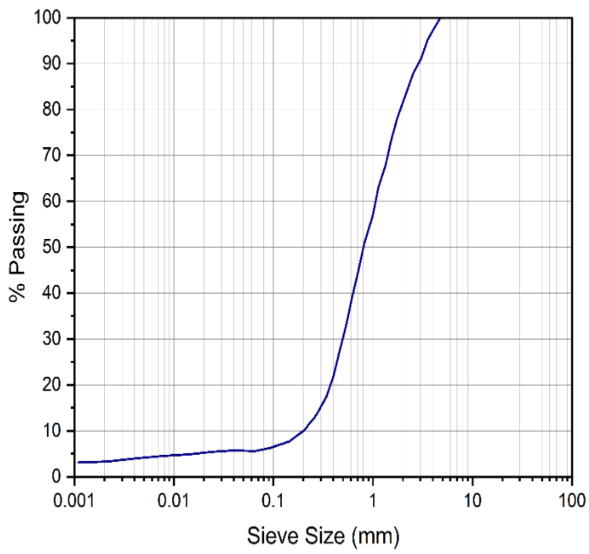

Figure 2: PSD of crusher run dust.

3.3 Super plasticiser

The concrete mix required the addition of a superplasticizer (MarkPlast-200F) to be usable. The amount of superplasticizer was chosen depending on how many slump trails were taken. Concrete slump was kept within a 76mm and 85mm range. A certain amount of superplasticizer was added to make it work with the weight of the cement. Table 4 presents the properties of the superplasticizer.

Table 4: Properties of superplasticizer

Properties	**Superplasticizer**
Name	MarkPlast-200F
Colour tone	Dark Brown
State	Liquid
Specific Gravity	1.06
Chemical Description	Polycarboxylate ether

3.4 Concrete

According to IS 10262:2019 [14], the concrete mix design for the M50 grade was created with a goal strength of 58.25 N/mm^2 and a planned mix proportion of 1:1.36:2.59 with a constant water-to-cement ratio of 0.38. Table 5 lists alternative mixture proportions.

Table 5: Mix Proportion for various concrete mixtures

Mixture	**CM**	**CD15**	**CD30**	**CD45**	**CD60**
w/c ratio	0.38	0.38	0.38	0.38	0.38
Water (kg/m^3)	170.60	170.60	170.60	170.60	170.60
Cement (kg/m^3)	448.95	448.95	448.95	448.95	448.95
Fine Aggregate (kg/m^3)	612	520.2	428.4	336.60	244.80
Coarse Aggregate (kg/m^3)	1167.2	1167.2	1167.2	1167.2	1167.2
Crusher run Dust (CD) (kg/m^3)	0	91.8	183.6	275.4	367.20
Super Plasticizer (% by weight of cement)	0.62%	0.60%	0.58%	0.52%	0.46%

4 Experiment Work

4.1 Preparation and testing of specimens

Crusher run dust, fine aggregate, coarse aggregate, and regular Portland Pozzolan cement were used to prepare the concrete. One of the six combinations was a control mix, while the remaining five contained various amounts of crusher run dust as a substitute for fine aggregate, including 15%, 30%, 45% and 60%. For casting, every component of the instrument was cleaned and carefully lubricated. Dimensional considerations were made, ensuring that no point or corner was overlooked as this could result in slurry leakage. Operations, including batching, mixing, and casting, were done meticulously. At first, aggregate weight was measured with a 0.5 g precision. Each component needed for each mix, including the cement, coarse aggregate (20 mm and 10 mm), fine aggregate, crusher run dust, superplasticizer, and water, was weighed separately. The materials were first combined evenly in dry form, and then a mixture of superplasticizer and water was added. The initial mixture was made by adding between 50% and 70% water, and it was then properly mixed for 3 to 4 minutes in the mixer. The remaining water was combined with the super-plasticizer and thoroughly swirled before being added to the already-made mixture in the mixer for 2 to 3 minutes. After the necessary amount of concrete was produced, it was ensured that it was compacted and that the concrete was properly poured into the moulds. Using a trowel, the top exterior of the filled mould was appropriately levelled. The prepared specimens were dried in the air for a whole day. Moulds were opened and the specimen was moved to a water tank for curing after the 24-hour casting period. After seven and twenty-eight days, the specimens were taken out of the tank. 21 samples for each mixture were created, including 6 cubes (150mm X 150mm X 150mm) for 7 and 28 days of compressive strength, 6 cylinders (300mm X 150mm) for split tensile strength at 7 and 28, 6 beams (100mm X 100mm X 500mm) for flexural strength at 7 and 28, and 3 cylinders (150mm X 100mm) for a porosity test at 28 days.

4.2 Mixture description

One concrete combination served as the control, and the other five were made with varying amounts of crusher-run dust. Mixtures were given the labels CM, CD15, CD30, CD45and CD60 for identification purposes. For instance, CD30 defines a concrete mix that includes crusher-run dust in place of 30% of the fine aggregate.

The results of the high-performance concrete investigation are greatly influenced by the experimental setup and conditions when using crusher-run dust to partially replace fine aggregate. Characteristics of materials, such as Portland Pozzolana cement, fine aggregates, coarse aggregates, and crusher-run dust, have a direct impact on the performance of concrete. Differences in mix ratios can change strength, workability, and durability. The precise amount of superplasticizer is important to keep the workability in the desired slump range; variations can result in mixes that are either too rigid or too watery, risking the structural strength. Accurate blending and measuring guarantee even the spread of substances, averting any potential flaws and fluctuations in performance. Appropriate curing conditions, such as temperature and humidity, are crucial for strengthening and decreasing porosity. Furthermore, it is essential to adhere to standardized testing conditions when assessing mechanical properties such as compressive strength, flexural strength, split tensile strength, and porosity to ensure accurate and dependable results. Changes in the conditions may lead to notable differences in the concrete's behaviour, complicating the determination of the effects of replacing fine aggregate with crusher-run dust.

5 Results and Discussion

5.1 Property of fresh concrete

Slump cone equipment was used to measure the slump values of various mixes. The concrete was treated with a superplasticizer to keep the slump value between 75mm and 85mm. Because of the larger particle size of crusher run dust compared to fine aggregate (as shown in Figure 2), slump values increased as the fine aggregate replacement increased proportionately, and the need for a superplasticizer to maintain slump decreased as a result. Details can be observed in Table 6, which shows that while the dust content in concrete in the crusher has increased, slump value has also increased, and superplasticizer content has reduced.

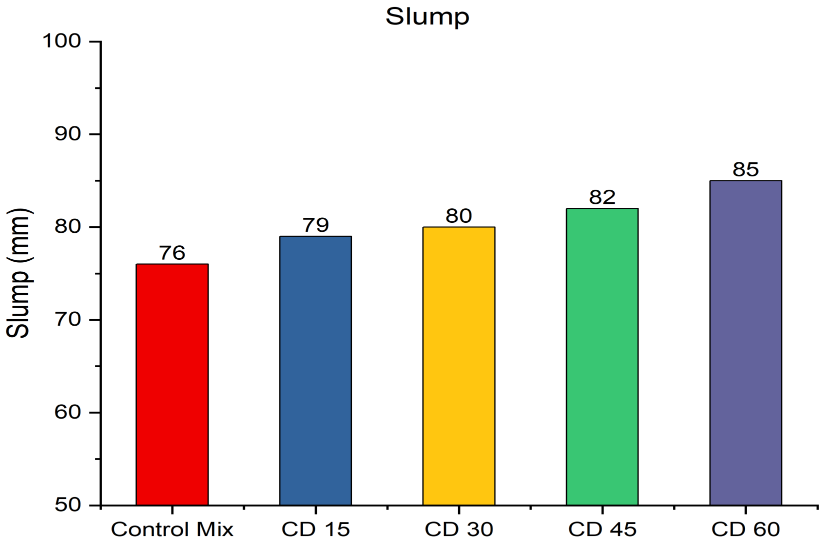

Figure 3: Details of superplasticizer and slump measurement.

Table 6: Details of superplasticizer and slump measurement

Replacement	Percentage of admixture	Slump (mm)
CM	0.62% of cement	76
CD15	0.60% of cement	79
CD30	0.58% of cement	80
CD45	0.52% of cement	82
CD60	0.46% of cement	85

5.2 Hardened properties of concrete

5.2.1 Compressive strength

The specimens' compressive strength was evaluated following IS 516-1959 (IS 516, 1959) The difference in average compressive strength for several specimens is depicted in Figure 4. For all combinations, the compressive strength increased from 7 days to 28 days. Additionally, it should be mentioned that compressive strength for the mixture of CD15 and CD30 was found to be higher than CM. Well-graded crusher-run dust particles, which tend to fill pores on a bigger scale and take part in chemical reactions at each stage of the strength-gaining process, are to blame for this favorable alteration. However, compressive strength started to decline as the percentage of fine aggregate substituted with crusher run dust reached 45%, i.e., for mix CD30, and compressive strength continued declining as the percentage of crusher run dust grew in the mix.

5.2.2 Split tensile strength

The specimens' split tensile strength was evaluated following IS 5816-1999 (IS 5816, 1999). The average split tensile strength change for several specimens is shown in Figure 5. For all blends, split tensile strength values increased from 7 days to 28 days. Additionally, split tensile strength values for mix CD15 and DC30 were found to be greater than CM. Due to the well-graded crusher-run dust particles' propensity to fill larger pores and take part in chemical reactions at each stage of the strength-gaining process, this noticeable variance was seen. However, as the substitution of fine aggregate with crusher run dust reached 30%, i.e., for mix CD30, split tensile strength decreased and continued to do so as the amount of crusher run dust in the mix increased.

5.2.3 Flexural strength

The specimens' flexural strength was evaluated following IS 516-1959 (IS 516, 1959) The average flexural strength variation for various specimens is depicted in Figure 6. For all combinations, flexural strength values increased from 7 days to 28 days. In addition to having higher compressive and split tensile strengths than CM, it was determined that the CD15 and CD30 mix have higher flexural strengths. Well-graded crusher-run dust particles, which have a propensity to fill pores on a bigger scale and take part in chemical reactions at each stage of the strength-gaining process, are to blame for this necessary alteration. However, the flexural strength of mix CD45 began to exhibit a fall when the amount of crusher run dust in the mix reached 45%, and it continued to decrease as the percentage of crusher run dust in the mix increased.

5.2.4 Porosity

The specimens underwent a porosity test following ASTM C64 (2006) (ASTM C64, 2006). Following a 28-day curing period, the porosity of concrete cylinders was assessed. As shown in Figure 6, crusher run dust has better-graded particles than fine aggregate, which increases strength by lowering the proportion of invisible pores. The final data in Figure 7 show that porosity values decrease up to 40.27% with an increase in replacement percentage at mix CD30; the lowest porosity value is attained. Even though the porosity of the mixes CD15, CD45 and CD60 improved, the final porosity was still lower than the CM.

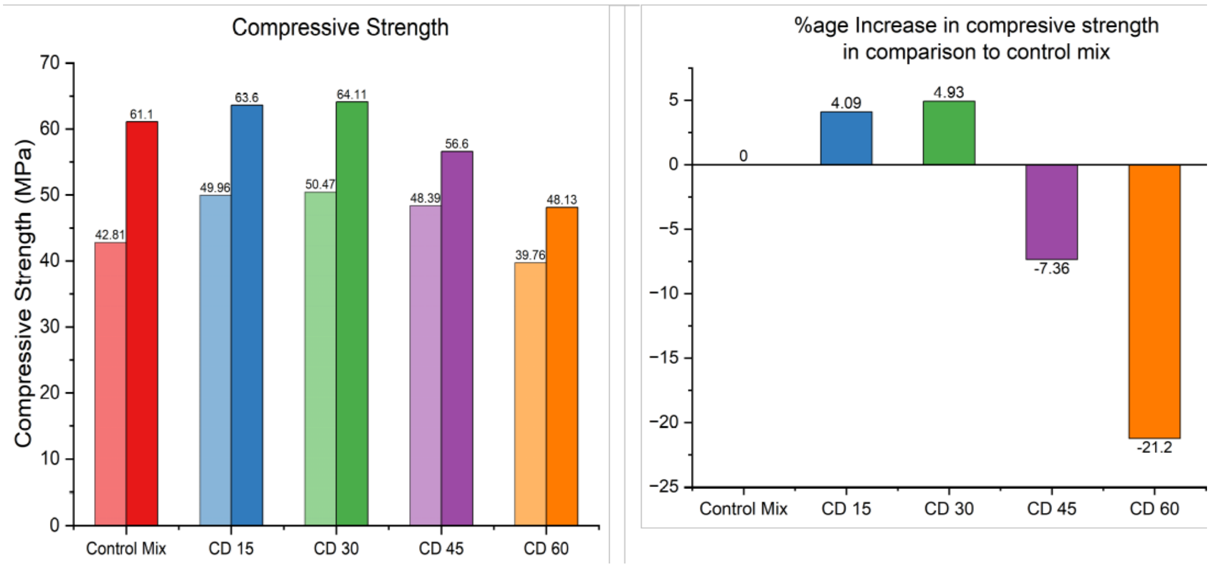

Figure 4: Compressive strength and Percentage increase in compressive strength in comparison to the control mix.

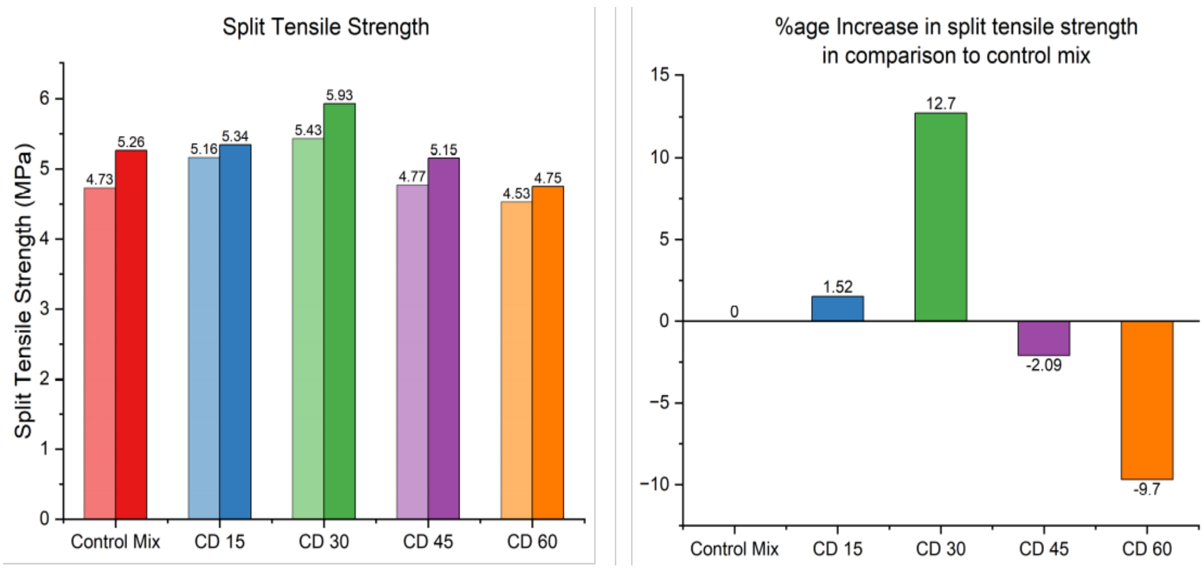

Figure 5: Split tensile strength and Percentage increase in split tensile strength in comparison to the control mix.

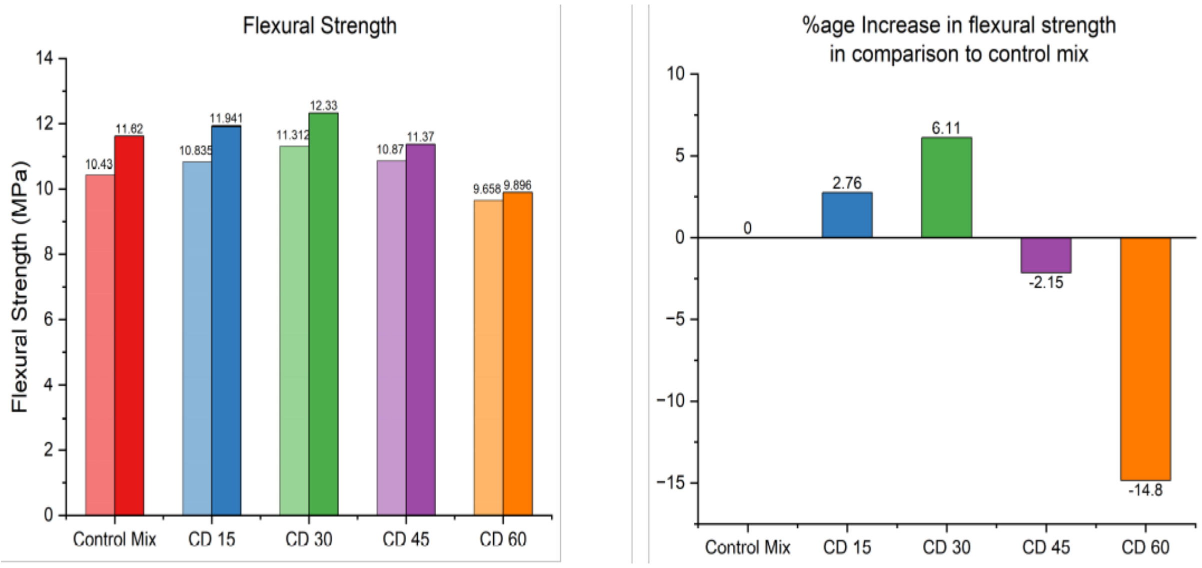

Figure 6: Flexural strength and Percentage increase in flexural strength in comparison to the control mix.

5.2.5 Multiple Regression Analysis

Multiple Linear Regression (MLR) analysis finds the line or curve best fitting a given data point set. Due to its simplicity, a direct relationship is frequently used to resolve many technical challenges. When modeling and analyzing correlations between two or more variables in the fields of engineering and science, regression analysis is a statistical technique that is particularly helpful [15–19].

In this research work, an attempt is made to apply the multiple linear regression models to predict the compression(C), split tensile (ST), and flexural strength (FS) of crusher run dust replaced concrete from slump value (SV) and porosity(P). The general representation of a probabilistic multiple linear regression model is presented in the following equation from Equations (1-6).

The provided multiple regression analysis equations serve as valuable tools in engineering for predicting the compressive, tensile and flexural strength of concrete at both early and long-term stages. The 7-day Compression equation estimates the concrete's compressive strength after seven days, a critical parameter for assessing early performance. It considers input factors like slump value, which measures workability and porosity. On the other hand, the 28-Day Compression equation predicts the concrete's compressive strength after 28 days, signifying its long-term durability and structural integrity. Similarly, equations 3 to 6 for ST and FS follow the same pattern. These equations also incorporate the same input factors. These equations are instrumental for engineers in ensuring the quality and suitability of concrete mixes for specific construction applications, aiding in structural design and performance assessment.

The experiment results showed a notable enhancement in the concrete's mechanical characteristics by substituting part of the fine aggregate with crusher-run dust. Higher percentages of crusher run dust resulted in increased compressive strength, split tensile strength, and flexural strength, with peak values attained at a 30% substitution level. In particular, the compressive strength experienced a 4.93% increase, split tensile strength saw a 12.70% increase and flexural strength showed a 6.11% increase in comparison to the control mix, which is confirmed by [20–24] The improvements result from the well-graded crusher-run dust particles that better fill the gaps and aid in the chemical reactions for hydration. After surpassing a 30% replacement level, the mechanical properties started to decrease, suggesting there was an ideal replacement threshold. Porosity examinations also confirmed these results, revealing a reduction in porosity of up to 30% when using replacements, which was closely linked to strength enhancement [25]. The research findings strongly support the advantages of incorporating crusher-run dust into concrete mixtures. This presents a sustainable and efficient substitute for natural sand that improves the strength and effectiveness of concrete buildings.

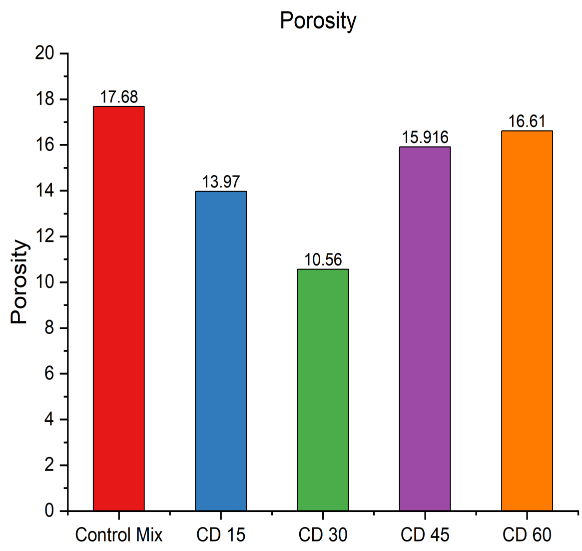

Figure 7: Average porosity (%) after 28 days.

6 Conclusion

The study presented a comprehensive analysis of the effects of curing time and fine aggregate substitution with crusher-run dust on the mechanical properties of concrete. Firstly, the research demonstrated that the mechanical qualities of concrete exhibit significant enhancement as curing time increases from 7 to 28 days. This finding aligns with established concrete curing principles, highlighting the importance of allowing sufficient time for concrete to attain its maximum strength. Moreover, the study identified a critical threshold at which a 30% substitution of fine aggregate with crusher run dust yielded maximum compressive strength, split tensile strength, and flexural strength, beyond which strength declined. This observation is vital for optimizing concrete mix designs, as it emphasizes the importance of balancing the use of crusher run dust to achieve the desired strength characteristics. Additionally, the slump cone test results indicated that increased crusher run dust led to improved workability, substantiating the potential benefits of the fine aggregate replacement. The noteworthy increase of 4.93% in compressive strength, 12.70% in split tensile strength, and 6.11% in flexural strength when 30% fine aggregate was substituted with crusher run dust further underscores the practical advantages of this substitution in enhancing concrete's mechanical properties. In conclusion, this study provides valuable insights and engineering justifications for optimizing concrete mix designs by considering both curing time and the percentage of crusher-run dust substitution, ultimately leading to developing more durable and high-performance concrete structures.

The results of this study have important consequences for both practical application and future research. Essentially, adding crusher-run dust as a substitute for fine aggregate in concrete mixes is a practical and efficient way to enhance concrete's mechanical characteristics like compressive, tensile, and flexural strengths. This replacement improves concrete performance and encourages the use of industrial by-products, aiding in waste reduction and environmental sustainability within the construction sector. These findings reveal new opportunities for investigating the ideal ratios of crusher-run dust in different concrete mixes and use in future studies. Additional research could examine the long-term durability of these modified concrete mixes and how they perform in various environmental conditions. Moreover, examining the economic advantages and life-cycle evaluation of incorporating crusher-run dust into concrete manufacturing might offer an all-encompassing comprehension of its viability as a common method in eco-friendly buildings.

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