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Experimental Investigation on Concrete Strength and Mechanical Properties Using Crushed Sandstone Dust as a Partial Replacement of Fine Aggregate

KHADKA CHANDRA BAHADUR[1], ASST. PROF. SURENDRA BAHADUR SHAHI[2]
[1, 2] Central Department of Civil Engineering, Graduate School of Engineering, Mid-West University, Birendranagar, Surkhet, Nepal

Abstract- ***In recent years, the problem of natural river sand scarcity and its environmental impact has triggered the need for sustainable alternative materials. Crushed Sand Stone Dust (CSSD) is a by-product of the stone industry, which is presented as a possible substitute for natural sands. In this paper, CSSD was used as a partial replacement for fine aggregate in concrete mixtures without any chemical admixtures. A constant water-cement (W/C) ratio of 0.45 was determined, and series of concrete cubes were prepared by replacing fine aggregate with CSSD in percentages of 0%, 10%, 20%, 30%, 40%, 50%.***

The fresh concrete workability was assessed using slump tests, while the hardened concrete properties were evaluated in terms of compressive, flexural strengths, and water absorption values at the ages of 7 and 28 days. The obtained results indicate the possibility of using CSSD as a partial replacement for fine aggregate in concrete production. The most efficient percentage of substitution was found to be 30%, where the compressive and flexural strengths of concrete reached their maximum. Specifically, at the age of 28 days, the compressive and flexural strengths were 47.03 MPa and 4.11 MPa, which is 8.2% and 23.4% higher than those of the ordinary concrete sample, respectively.

In addition, the water absorption was minimum at 30% substitution, reaching 1.03%. On the other hand, the concrete's mechanical properties decreased by 15.4% and 26.8% on average for compressive and flexural strengths, respectively, when exceeding the 30% CSSD replacement due to low workability and poor aggregate gradation.

Kry Words- Compressive strength, Crushed Sand Stone Dust, Fine aggregate, Flexural strength, Mechanical properties, Water absorption.

I. INTRODUCTION

Concrete is undoubtedly the most widely used construction material in the world today, and therefore its granular component is in great demand. Naturally occurring river sand has long been the universal fine aggregate in concrete due to its optimal spherical shape and gradation. However, its excessive exploitation has led to its significant depletion, regulatory restrictions, and high prices. Moreover, the process of crushing stone aggregates generates enormous amounts of dust, which is a waste product. The dust generated by crushers not only clogs adjacent crops but also violates air quality standards, posing a serious threat to the health of residents near these facilities, such as silicosis and lung disease.

The utilization of industrial waste rock from parent rock as an aggregate filler in concrete not only solves the problem of river sand excavation but also recovers associated waste from industrial conglomerates. The use of waste rock dust in concrete has been the subject of many studies.

However, research often uses a mixture of quarry materials or requires superplasticizer additions to achieve the necessary consistency. In addition, in most cases, the mineralogical composition of rocks was not indicated. This study examines the structural properties of sandstone quarry waste dust (CSSD) used as a fine aggregate filler. Particular attention is paid to the concrete mixture made from the crusher dust of one deposit (Tilpur crusher, Birendranagar 9, Surkhet), without the addition of any admixtures.

The accumulation of crusher dust poses disposal challenges for industry owners. Therefore, its utilization in construction materials such as mortar, concrete, and composites is both economically and environmentally beneficial [8-10]. Several industrial by-products, including fly ash, slag, limestone powder, and stone dust, have been successfully used in concrete [11, 12]. The use of crusher stone dust as a partial or full replacement for river sand not only reduces environmental impact but also improves the economic feasibility of construction projects. Previous studies have indicated that it can provide comparable strength and performance, particularly in medium grade several construction products [6, 7, 13]. This study aims to investigate the suitability of crusher stone dust as a replacement for natural sand in concrete.

II. RESEARCH ELABORATIONS

A. Material Selection and Characterization:

All primary experimental matrices utilize locally sourced ingredients to replicate conventional structural applications.

Cement: Ordinary Portland Cement (OPC) Grade 43 meeting IS 8112 guidelines were procured from a singular lot to guarantee chemical constancy, exhibiting a specific gravity of 3.15 and a standard consistency of 29%.

Aggregates: Coarse components comprised crushed gravel blended from 10 mm and 20 mm size fractions. Conventional fine aggregate consisted of natural river sand falling into Zone II grading.

Crushed Sand Stone Dust (CSSD): The mineral waste under investigation was retrieved out of a specific regional processing plant and tested clean of organic contamination, mapping into fine Zone IV grading characteristics under IS 383.

Table 1: Physical Parameters of Raw Materials

Physical Engineering Properties	Fine Aggregate	10 mm Coarse	20 mm Coarse	Crusher Stone Dust
Specific Gravity	2.61	2.65	2.69	2.52
Water Absorption (%)	1.10	0.70	0.46	2.88

B. Mix Proportioning and Matrix Design:

Mix formulations were developed according to IS 10262 design norms for medium-grade structural building specifications. The water-cement ratio was held completely constant at 0.45 across all variants, alongside a baseline HRWR percentage of 0.5%. Fine aggregate was sequentially substituted with CSSD from 0% to 50% using a step value of 10%.

Table 2: Exact Mix Quantities for Concrete Series

Mix Code	Cement (kg/m3)	Water (kg/m3)	Fine Sand (kg/m3)	Coarse 10mm (kg/m3)	Coarse 20mm (kg/m3)	CSSD (kg/m3)
CSD0	425.73	191.58	649.92	570.27	570.27	0.00
CSD10	425.73	191.58	584.93	570.27	570.27	64.99
CSD20	425.73	191.58	519.94	570.27	570.27	129.98
CSD30	425.73	191.58	390.07	570.27	570.27	194.98
CSD40	425.73	191.58	390.11	570.27	570.27	259.81
CSD50	425.73	191.58	324.96	570.27	570.27	324.76

C. Testing Protocols and Standards:

Fresh workability was evaluated immediately upon discharge using standard slump cone apparatus following IS 1199 parameters. Cube elements of dimensions 150 x 150 x 150 mm were used for compressive testing, and beam prisms of dimensions 100 x 100 x 500 mm were used for single center-point flexural testing under IS 516 constraints. Cured cubes underwent water absorption evaluation at 28 days via saturated/oven-dried measurement protocols designated by ASTM C642.

III. RESULTS AND FINDINGS

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A. Fresh State Properties (Workability):
Slump measurements reveal a continuous drop in internal fluidity values as the CSSD mineral fraction scales upward within the mix matrix.

Fig 1: Slump Test of Concrete

Table 3: Workability Trends across Experimental Concrete Groups

Parameter Metric	CSD0	CSD10	CSD20	CSD30	CSD40	CSD50
Measured Slump (mm)	86	85	84	81	77	72

This continuous drop stems directly from the microstructural morphology of the crusher dust. Sandstone dust features significantly rougher surface topology and highly angular geometry compared to natural river sand. This sharp configuration raises internal interparticle friction forces, drawing extra free hydration water to wet its high specific surface area, which decreases the overall slump. Crucially, replacement levels up to 30% maintain workable slump values within a highly satisfactory range (81 mm).

Fig 2: Compressive Strength test of Concrete Cube

B. Compressive Strength Performance:
Compressive capacity data gathered at 7-day, and 28-day intervals reflects notable strength enhancement peaking precisely at the 30% substitution mark.

Table 4: Compressive Strength Profiles across Substitution Ranges

Age Interval	CSD0 (Control)	CSD10	CSD20	CSD30 (Optimum)	CSD40	CSD50
7-Day Cured (MPa)	28.77	28.89	30.00	31.84	28.60	27.25
28-Day Cured (MPa)	43.47	44.04	44.59	47.03	43.57	42.51

The progressive development in compressive values up to 30% replacement originates from physical particle packing mechanisms. Very fine crusher dust particles fit neatly inside the micro-void channels formed within hydrated cement paste networks and the interfacial transition zones (ITZ). This micro-filler effect consolidates internal density while reducing internal porosity. However, scaling CSSD substitution past 30% results in performance loss. This downturn is tied directly to poor mechanical compaction caused by low workability, which yields internal structural microvoids that weaken the hardened core.

C. Flexural Strength Performance:

Flexural characteristics demonstrate parallel structural behavior, showing considerable improvements across the entire initial substitution sequence.

Fig: 3 Flexural Strength Test of Concrete Beam

Table 5: Flexural Resistance Performance Matrices

Curing Duration	CSD0	CSD10	CSD20	CSD30	CSD40	CSD50
7-Day Cured (MPa)	2.22	2.31	2.52	3.05	2.20	2.00
28-Day Cured (MPa)	3.33	3.39	3.59	4.11	3.50	3.28

The peak performance observed at 30% replacement represents a 37.4% strength gain at 7 days and a 23.4% strength gain at 28 days compared to the control group. The angular characteristics and rougher faces of the crushed sandstone grains improve mechanical interlocking with the surrounding cementitious binder. This enhanced bond strengthens the flexural resistance of the concrete prisms against tensile failure.

D. Durability: Water Absorption

Water absorption measurements validate the micro-structural filler hypothesis by confirming enhanced impermeability up to the optimal replacement level.

Fig 4: Water absorption test of Concrete Cube

The control mix exhibited a baseline absorption of 1.38%. Sieve filler efficiency minimized this index to 1.03% at the 30% replacement level, proving that denser aggregate packing blocks potential moisture ingress pathways. Past 30%, absorption levels climb back up to 1.44% because poor workability makes the fresh mix difficult to compact thoroughly, leaving interconnected voids in the hardened matrix.

IV. CONCLUSION

Experimental testing demonstrates that crushed sandstone dust can successfully serve as a reliable, green, and cost-effective substitute for natural river sand in structural concrete. Incorporating rough, angular sandstone fine aggregates reduces fresh mix workability but significantly enhances mechanical performance when properly proportioned. The optimal fine aggregate substitution level is determined to be exactly 30%. At this replacement level, concrete achieves its highest compressive strength (47.03 MPa), peak flexural resistance (4.11 MPa), and lowest overall water absorption (1.03%). Using this industrial waste resource offers structural concrete projects an eco-friendly path forward, lowering overall materials costs while actively conserving diminishing river sand reserves.

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