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Synergistic Blending of Natural and Crushed Sand for Sustainable and High-Performance Concrete

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Abstract

This paper investigates the synergistic blending of natural and crushed sand to optimize cement concrete formulations, achieving strength grades from C20 to C50 while improving workability. Experimental results showed optimal mixing sand ratios of 3:1 and 2:1 for low-grade (C20~C25) and high-grade (C40~C50) concrete, respectively, to achieve the most favorable working state and optimal compressive strength at 28 days. Economic feasibility analysis also revealed a significant cost advantage of using mixed sand in concrete construction compared to natural sand-based concrete productions. These findings highlight the sustainable and economic benefits of integrating mixed sand in construction projects.

Overall, the study presents valuable insights for industry professionals, emphasizing the positive implications of adopting mixed sand in concrete construction. The identified optimal blending ratios and economic advantages contribute to the growing body of knowledge in sustainable and high-performance concrete formulations, enriching our understanding of innovative approaches in the construction industry.

Keywords: Concrete Blending, Natural Sand, Crushed Sand, Optimal mixing ratios, economic benefits

1. Introduction

Concrete is a ubiquitous construction material whose properties are largely determined by its constituent aggregates. Natural sand is the most commonly used fine aggregate in concrete, but it is becoming increasingly scarce and expensive. Crushed sand, a byproduct of the quarrying industry, is a sustainable and cost-effective alternative to natural sand. Blending natural and crushed sand in concrete has been shown to offer a number of advantages, including improved compressive strength, workability, durability, and sustainability.

A number of studies have investigated the impact of sand blending on the fresh and hardened properties of concrete. Chen et al. (2019) found that blending natural and crushed sand improved the workability of concrete without compromising compressive strength. Garcia and Martinez (2020) reported that sand blending can also improve the rheological properties of concrete, making it easier to transport and place. In terms of hardened concrete properties, Patel et al. (2017) found that blending natural and crushed sand reduced the permeability of concrete, thereby improving its durability against environmental factors. Nguyen and Lee (2019) reported that sand blending can improve the flexural strength of concrete.

Kim and Park (2018) investigated the long-term behavior of concrete with blended sands and found that it exhibited lower creep and shrinkage than concrete with natural sand alone. This suggests that blended sand concrete may be more durable in long-term applications. Li et al. (2016) investigated the influence of sand blending on the microstructure and porosity of concrete. They found that blended sand concrete exhibited a denser and more uniform microstructure, which contributed to its improved mechanical and durability properties.

In addition to the fresh and hardened properties, other factors such as the particle size distribution of the sand blend and the interactions between sand blending and chemical admixtures can also affect the performance of concrete. Yang et al. (2021) found that optimal particle size distribution of the sand blend is essential for achieving desirable concrete properties. Liu and Wang (2020) reported that sand blending can interact with chemical admixtures in complex ways, and careful consideration is required to design concrete mixes with blended sands.

The literatures consistently highlights the potential advantages of incorporating both natural and crushed sand into concrete, showcasing improvements across various dimensions such as fresh and hardened properties, long-term behavior, as well as microstructure and porosity. Nevertheless, a key consideration that emerges from these studies is the crucial importance of meticulously addressing the particle size distribution in formulating concrete mixes involving blended sands. This becomes particularly pertinent in the context of Ethiopia, where the escalating number and scale of infrastructure projects have resulted in an increased demand for sand to be utilized in cement and concrete. Intriguingly, despite this surge in demand, the engineering characteristics of natural sand in Ethiopia often translate into elevated costs and suboptimal concrete performance. Recognizing this challenge, our paper proposes a pragmatic solution: a blending scheme that combines natural sand and crushed sand in carefully calibrated proportions for concrete formulation. The

significance of this proposed scheme is validated through thorough lab tests on concrete mixes. Notably, the implementation of this blending strategy not only mitigates the challenges arising from the scarcity of natural sand in projects but also stands out for its potential to curtail project costs while concurrently enhancing the overall performance and usability of concrete. In essence, this proposed scheme not only addresses the immediate constraints imposed by the scarcity of natural sand but also represents a strategic move towards cost-effectiveness and improved concrete functionality in the Ethiopian construction landscape.

2. Materials and Methods

In conducting the experimental procedures, this study meticulously adhered to the JTG/T F50-2011 Technical Specifications. This included comprehensive standards for testing coarse aggregates, crushed sand, and natural sand, ensuring rigorous evaluation of their engineering technical indexes. These standards covered critical parameters such as mud content, water absorption, crushing resistance, and organic matter content. Additionally, for concrete mix design, as well as the physical and mechanical characterization of cement, the strictly followed the ASTM standards. These standards provided a detailed framework for assessing cement consistency, setting time, compressive strength & other key properties. Adherence to these globally recognized standards ensured the reliability and validity of reported test results

2.1 Engineering Technical Index of Ethiopian Natural Sand

The evaluation of natural sand in Ethiopian construction projects is vital, considering the ongoing trend of relaxing certain technical requirements, especially when mud content and sand grading meet specifications. This leniency is influenced by the limited supply and availability of natural sand in close proximity to project sites. However, strict adherence to technical specifications might disqualify a significant portion of supplied natural sand. This paper aims to provide a nuanced understanding of Ethiopian natural sand, drawing insights from diverse perspectives and technical specifications.

Technical Indicators and Evaluation:

Five representative technical indicators of natural sand, as outlined in clause 6.3.1 and 6.3.4 of JTG/T F50-2011 Technical Specification for the Construction of Road Bridges and Culverts, are crucial for the evaluation process (Table 1 and 2). These indicators include mud content, water absorption, light matter content, crushing resistance, organic matter content, and void ratio.

Table 1 Technical Index of Ethiopian Natural Sand

Technical Index / Status/No.		Mud Content (%)	Angularity (S)	Water Absorption (%)	Apparent Density (g/cm^3)	Organic Matter (%)	Light Matter (%)	Crushing Value (%)	Bulk Density (g/cm^3)	Air Void (%)
Original State Natural Sand	1#	7.2	17.0	5.45	2.52	Failure	3.5	25.5	1.24	50.8
	2#	11.6	17.0	5.78	2.528	Failure	8.4	26.9	1.21	52.1
	3#	10.1	16.3	5.41	2.519	Failure	3.2	28.8	1.19	52.8
	4#	4.2	17.3	5.56	2.511	ok	4.8	26.1	1.23	51.0
	5#	5.2	18.0	5.45	2.511	Failure	9.7	22.8	1.23	51.0
	1#	3.3	15.0	3.99	2.571	ok	3.0	25.2	1.25	51.4

Technical Index / Status/No.		Mud Content (%)	Angularity (S)	Water Absorption (%)	Apparent Density (g/cm^3)	Organic Matter (%)	Light Matter (%)	Crushing Value (%)	Bulk Density (g/cm^3)	Air Void (%)
Natural Sand After Water Washing	2#	2.2	15.2	4.02	2.566	ok	8.0	27.1	1.22	52.5
	3#	2.8	16.7	4.13	2.572	ok	2.8	28.5	1.20	53.3
	4#	1.9	15.8	3.95	2.574	ok	4.5	25.8	1.21	53.0
	5#	1.5	15.8	3.91	2.571	ok	9.2	22.7	1.21	52.9
JTG/T F50-2011	I	≤2	—	—	≥2.5	ok	≤1%	<20	>1.35	<47
	II	≤3	—	—				<25		
	III	≤5	—	—				<30		

Table 2 Analysis of The Grade of Natural Sand in Ethiopia

Control Sieves / Passing Rate		9.5mm	4.75mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm	Fineness Modulus
Original State Natural Sand	1#	96.40	92.40	85.50	69.20	55.20	24.20	9.80	2.36
	2#	96.00	92.70	84.80	67.80	53.90	27.20	14.10	2.33
	3#	97.30	94.20	86.80	70.30	56.00	25.00	12.10	2.34
	4#	97.90	94.10	85.00	66.60	50.70	19.40	5.90	2.58
	5#	98.60	95.00	86.60	68.40	53.60	22.80	9.40	2.46
Natural Sand After Water Washing	1#	96.30	92.10	84.80	67.70	53.10	20.60	5.50	2.48
	2#	95.70	92.00	83.40	64.80	49.70	20.60	6.30	2.56
	3#	97.10	93.80	85.80	67.90	52.50	19.00	5.00	2.54
	4#	97.80	94.00	84.70	65.90	49.60	17.60	3.80	2.64
	5#	98.50	94.70	86.00	67.00%	51.50	19.20	5.30	2.58
JTG/T F50-2011	I	/	90~100	65~95	35~65	15~29	5~20	0~10	3.7~3.1
	II	/	90~100	75~100	50~90	30~59	8~30	0~10	3.0~2.3
	III	/	90~100	85~100	75~100	60~84	15~45	0~10	2.2~1.6

Analysis of Original Natural Sand:

The original form of Ethiopian natural sand, as depicted in the technical indicators presented, reveals undesirable engineering characteristics (Table 1). This includes a substantial mud content, high water absorption, light matter content, poor crushing resistance, organic matter content, and a large void ratio. Importantly, these characteristics create a significant gap with the specified requirements, emphasizing the need for thorough assessment and potential remediation.

Water Washing Method:

To address the identified defects, the water washing method emerges as a viable solution. High mud content and unqualified organic matter in natural sand can be effectively mitigated through this process, aligning the sand more closely with technical specifications. Post-washing, improvements are observed in fluidity, gradation, apparent density, and water absorption to varying degrees, indicating a notable enhancement in meeting technical requirements (Table 2).

Effectiveness of Water Washing Method:

However, a detailed analysis of technical indicators, specifically light matter content, crushing value, porosity, and loose packing density before and after washing, reveals minimal changes. This suggests that while the water washing method is effective in enhancing certain characteristics, it does not substantially impact others. This nuanced understanding emphasizes the selective influence of water washing in the improving specific engineering properties.

The technical evaluation of Ethiopian natural sand underscores the complexities associated with its original natural sand form and the potential for improvement through the water washing method. This analysis, grounded in diverse technical perspectives and specifications, provides valuable insights for optimizing the selection and treatment of natural sand in construction projects.

2.2 Engineering Technical Index of Crushed Sand

In the Ethiopian construction landscape, the prevalence of widespread, abundant, and easily extractable basaltic rock has positioned crushed sand as a promising alternative. The innate advantages of crushed sand, including a wide source, material stability, ease of extraction, operational simplicity and economic feasibility are critical considerations. This paper aims to present a comprehensive technical evaluation of crushed sand, drawing insights from diverse perspectives and specific technical specifications.

Technical Specifications and Evaluation:

Five representative technical specifications of crushed sand, as outlined in clause 6.3.1 and 6.3.4 of JTG/T F50-2011 for the Construction of Road Bridges and Culverts, form the basis for this evaluation (Table 3 and Table 4). These pecifications cover critical aspects such as water absorption, particle cleanliness, resistance to crushing, porosity, and harmful substance content

Table 3 Technical index of Crushed Sand in Ethiopia

Technical Index / Status/No.		Filler Value (%)	Mb Value (g/kg)	Water Absorption (%)	Apparent Density (g/cm^3)	Organic Matter (%)	Light Matter (%)	Crushing Value (%)	Bulk Density (g/cm^3)	Air Void (%)
Crushed Sand	1#	15.5	1.3	2.67	3.015	ok	0	12.6	1.71	43.3
	2#	13.9	1.3	3.45	2.701	ok	0	13.9	1.51	44.1
	3#	11.7	1.2	3.34	2.747	ok	0	14.8	1.47	46.5
	4#	9.8	1.1	2.49	2.986	ok	0	14.2	1.62	45.7
	5#	8.6	1.3	2.85	2.994	ok	0	13.5	1.6	46.6
JTG/T F50-2011	I	≤10.0	<1.4	—	≥2.5	ok	≤1	<20	>1.35	<47
	II	≤7.0		—				<25		
	III	≤5.0		—				<30		

Table 4 Analysis of The Gradation of Ethiopian Crushed Sand

Control Sieves / Passing Rate		9.5mm	4.75mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm	Fineness Modulus
Crushed Sand	1#	100	100	96.4	58.9	41.3	26.3	20.7	2.56
	2#	100	100	91.3	52.5	36.6	23.3	18.1	2.78
	3#	100	100	91.7	50.6	31.2	19.0	14.6	2.93
	4#	100	100	80.9	44.8	31.4	16.9	12.2	3.14
	5#	100	100	70.1	41.3	27.9	16.8	11.8	3.32

Analysis of Technical Indicators:

Upon detailed analysis, the technical indicators highlight the engineering prowess of crushed sand. Notably, crushed sand exhibits small water absorption, clean particles, robust resistance to crushing, and

minimal harmful substances, aligning well with stringent technical specifications. However, challenges arise in the gradation of crushed sand, revealing a poor distribution with higher Passing Rates at the ends and lower in the middle.

Practical Application on Addis Ababa - Adama Expressway:

The practical application of crushed sand and its comparison with natural sand on the Addis Ababa - Adama Expressway provides invaluable insights. The primary distinction lies in the engineering characteristics, where natural sand boasts rounded particles, a smooth surface, reasonable particle distribution, and good gradation, enhancing its compatibility with concrete. Conversely, crushed sand, while excelling in crush resistance, cleanliness, and reduced water absorption, presents challenges such as sharp and rough particles, a large fineness modulus, poor grading, and the presence of needles and flakes. These characteristics contribute to poor workability, segregation, and slurry formation in the concrete mix.

Optimizing Concrete Mix Design:

In next section, to capitalize on the advantages of both sand types and mitigate their individual challenges, a proportionate blend of natural sand and crushed sand in concrete mix design is proposed. Effective mastery of this blended approach ensures optimal workability, physical and mechanical properties, and long-term durability, leading to the creation of high-performance concrete. This proposition is grounded in a synthesis of various technical specifications and practical insights, contributing to the ongoing discourse on effective sand utilization in Ethiopian construction practices.

The engineering technical assessment of crushed sand in Ethiopian construction reveals a nuanced landscape. While crushed sand brings commendable advantages, its unique challenges necessitate a thoughtful blend with natural sand. This approach, underlined by a diverse set of technical specifications and practical applications, aims to achieve a harmonious balance in concrete mix design. The findings contribute to the evolving understanding of sand utilization, fostering sustainable and effective practices in Ethiopian construction endeavors.

3. Test results of mixed sand configuration concrete scheme

Specifically, for aggregate testing, this study utilized standards methods such as ASTM C136 for sieve analysis, ASTM C127 for specific gravity and absorption of coarse aggregate, and ASTM C131 for resistance to degradation. For cement analysis, tests included ASTM C109 for compressive strength, ASTM C191 for setting time, and ASTM C204 for fineness by air-permeability apparatus.

3.1 Cement

"Mugher" 42.5 grade ordinary silicate cement, is known for its consistent quality and widespread usage in construction projects across Ethiopia. Produced by the Ethiopian National Cement Factory, this cement serves as the fundamental binding agent in the experimental concrete blends. Various tests were meticulously conducted to gauge a range of physical and mechanical characteristics inherent to the "Mugher" cement. These tests, aligned with industry standards, encompass critical various parameters and the outcomes of the tests are encapsulated in the test result performance indexes, as detailed in Table 5.

3.2 Coarse Aggregate

Coarse aggregate, specifically utilizing basalt continuous graded aggregates ranging from 5mm to 14mm and 14mm to 25mm in a 2:3 combination, produced in the K-4 yard of Addis Ababa-Awash Expressway (Table 6).

The chosen coarse aggregate plays a vital role in determining the structural properties of the concrete. The incorporation of basalt aggregates in varying size fractions and proportions aims to investigate their impact on the overall performance of the concrete mix. The subsequent results of this investigation will shed light on the suitability and effectiveness of the chosen coarse aggregate combination in enhancing the properties of the cement concrete.

3.3 Fine Aggregate

Two types of fine aggregates were employed in this study. Fine aggregate #1 consists of 0~3mm basaltic crushed sand produced by the K40 material yard of the Addis Ababa-Awash Expressway. On the other hand, fine aggregate #2 comprises washed natural sand sourced from the AWASH sand yard.

The study incorporates these distinct fine aggregates to assess their influence on the overall performance of the cement concrete. By presenting detailed indexes, the investigation aims to provide a comprehensive understanding of how the blending of natural and crushed sands impacts the key properties of the concrete mix, contributing valuable insights to the broader field of concrete material science.

Table 5 Physical and Mechanical Indexes of Cement

Cement Variety	Fineness (%)	Adequacy (mm)	Setting Time (Min)		Bending Strength (MPa)		Compressive Strength (MPa)	
			Initial	Final	3d	28d	3d	28d
P.O 42.5	1.8	1.5	108	165	6.1	8.4	27.7	47.1

Table 6 Physical and Mechanical Indexes of Coarse Aggregates

Aggregate Type	Crushing Value (%)	Water Absorption Rate (%)	Apparent Density (g/cm^3)	Loose Stacking Density (g/cm^3)	Air Void (%)	Needle And Flake Content (%)	Mud Content (%)
5~14mm	14.1	1.99	2.813	1.62	41.8	14.8	0.5
14~25mm	12.3	1.85	2.769			12.5	0

Table 7 Physical and Mechanical Indexes of Different Blending Ratios

Technical Index / Status/No.		Filler Value (%)	Mb Value (g/kg)	Water Absorption (%)	Apparent Density (g/cm^3)	Organic Matter (%)	Light Matter (%)	Crushing Value (%)	Bulk Density (g/cm^3)	Air Void (%)
Pure Crushed Sand		10	1.4	2.43	2.991	/	0	3.3	1.71	42.8
Crushed Sand: Natural Sand	3:1	7.8	1.4	2.85	2.878	/	0.5	13.7	1.61	44.1
	2:1	7.0	1.3	2.98	2.843	/	0.7	14.4	1.55	45.5
	1:1	5.5	1.3	3.26	2.774	/	1.0	15.3	1.50	45.9
	1:2	4.0	1.2	2.53	2.708	/	1.3	16.2	1.45	46.5
	1:3	3.3	1.2	3.67	2.677	/	1.5	19.8	1.41	47.3
Pure Natural Sand		1.0	1.2	4.08	2.586	/	2.0	30.5	1.30	49.7
JTG/T F50-2011	II	≤7.0	<1.4	—	≥2.5		≤1	<25	＞1.35	<47
	III	≤5.0		—				<30		

Table 8 Gradation Analysis of Different Blending Ratios

Crushed Sand: Natural Sand	9.5mm	4.75mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm	Modulus Fineness
Pure Crushed Sand	100	100	88.7	46.4	32.5	19.1	12.6	3.01
3:1	100.0	99.4	89.6	52.3	37.3	19.3	11.1	2.89
2:1	100.0	99.2	89.9	54.3	38.9	19.4	10.5	2.85
1:1	100.0	98.8	90.5	58.3	42.1	19.5	9.5	2.78
1:2	100.0	98.4	91.0	62.2	45.2	19.6	8.5	2.70
1:3	100.0	98.2	91.3	64.2	46.8	19.7	8.0	2.66

In the investigation of fine aggregates for the performance of cement concrete prepared by blending natural sand with crushed sand, the focus lies on the blending of natural sand with crushed sand, as detailed in Table 7 and 8. The findings from this analysis reveal crucial insights into the characteristics and performance of the fine aggregates.

1. Gradation Improvement with Natural Sand Blending:

With an increase in the proportion of natural sand blending, the gradation of crushed sand demonstrates a gradual improvement. The distribution across each grade tends to become more rational, meeting the gradation requirements. This enhancement is particularly noteworthy when compared to the original gradation of crushed sand. The findings suggest that the incorporation of natural sand contributes to a more balanced and well-graded fine aggregate, essential for meeting construction standards.

2. Physical Property Enhancements with Crushed Sand Blending:

Conversely, an elevation in the proportion of crushed sand blending results in notable improvements in various physical properties. The water absorption of the mixed sand decreases, accompanied by reductions in the content of light matter and porosity. Simultaneously, there is a gradual increase in the apparent density of the blended sand. These improvements collectively contribute to enhanced crushing resistance and overall performance indicators, showcasing substantial advancements when compared with concrete mixes utilizing only natural sand. This suggests that the addition of crushed sand contributes positively to the mechanical and durability characteristics of the concrete, making it a valuable component in the blending process.

In summary, the exploration of fine aggregates in this study reveals that the strategic blending of natural and crushed sands can lead to significant improvements in gradation and physical properties, ultimately influencing the overall performance of the cement concrete.

3.4 High Efficiency Water Reducing Additive

In the investigation of the performance of cement concrete prepared by blending natural sand with crushed sand, the

experimental process includes a crucial element regarding the use of JD-2 Poly carboxylic acid slow-setting water reducing agent, produced by Beijing Jindun Building Material Co. This high-efficiency water reducing additive plays a pivotal role in optimizing concrete mixes, controlling water content, and enhancing workability while influencing key properties like setting time and compressive strength.

Table 9 provides an insightful overview of the main performance indexes of JD-2, encompassing water reduction efficiency,

setting time, compressive strength enhancement, and consistency. The detailed analysis of these performance indexes serves as a valuable reference, highlighting the specific contributions of JD-2 to the fresh and hardened properties of the cement concrete, thereby emphasizing its significance in the quest for improved concrete performance.

Table 9 Main Performance Indexes of High Efficiency Water Reducing Agent

Water Reduction Rate (%)	Air Content (%)	Chlorine Content (%)	Water Secretion Ratio (%)		Compressive Strength Ratio (%)		Shrinkage Ratio (%)	Loss of Warp Time (mm)
			Normal Pressure	Pressure	7d	28d		
33	2.6	0.1	0	70	196	180	101	30

4. Workability and Mechanical Properties of Concrete Mixed with Sand

4.1 Determination of Concrete Mix Ratio

The study involved a thorough analysis of the concrete mix ratio, specifically focusing on the impact of different unit cement dosages, represented by varying water-cement ratios, on the selection of the optimal blending ratio for mixed sand. To facilitate a comprehensive performance comparison, two groups with distinct cement dosages were selected, each incorporating seven different blending ratios of mixed sand. These ratios ranged from pure crushed sand to pure natural sand in proportions of 3:1, 2:1, 1:1, 1:2, and 1:3. The adjustment of unit water consumption and sand rate within each concrete group was guided by the unique engineering technology characteristics of the mixed sand, ensuring uniform initial slump (210±10mm) and optimal compatibility. This particular process, involving repeated adjustments, was undertaken to establish precise concrete mix ratios that would contribute to the desired properties and performance of the cement concrete. The determination of these mix ratios is integral to understanding how the combination of natural and crushed sands influences the overall performance of the concrete under varying unit cement dosages.

Table 10 The Amount of Each Material for The Test Ratio (kg/m^3)

Test NO.	Crushed/Natural Sand Ratio	Cement (kg)	Water (kg)	(14~25) mm Aggregates (kg)	(5~14) mm Aggregates (kg)	Crushed Sand (kg)	Natural Sand (kg)	Water Reducing Additive (kg)
C50-1	Pure Crushed Sand	490	146	694.2	462.8	680.2	0	7.35
C50-2	3:1	490	152	678.6	452.4	477.6	159.2	7.35
C50-3	2:1	490	154	672.9	448.6	421.0	210.5	7.35
C50-4	1:1	490	155	677.5	451.7	304.3	304.3	7.35
C50-5	1:2	490	157	679.0	452.6	194.5	389.0	7.35
C50-6	1:3	490	159	675.0	449.4	144.8	434.5	7.35
C50-7	Pure Natural Sand	490	162	674.3	449.5	0	554.1	7.35
C20-1	Pure Crushed Sand	300	160	647.5	431.7	920.3	0	3.9
C20-2	3:1	300	164	653.0	435.3	641.9	214.0	3.9
C20-3	2:1	300	165	649.5	433.0	567.6	283.8	3.9
C20-4	1:1	300	166	654.1	436.0	411.6	411.6	3.9

C20-5	1:2	300	167	647.3	431.5	271.5	543.1	3.9
C20-6	1:3	300	168	655.6	437.0	198.0	594.0	3.9
C20-7	Pure Natural Sand	300	168	655.6	437.0	0	780.2	3.9

As evidenced by Table 10, several noteworthy observations emerge regarding the determination of concrete mix ratios in the performance of cement concrete prepared by blending natural sand with crushed sand:

1. For concrete mixtures of the same grade (equivalent cement dosage), a discernible trend is observed wherein an increase in the proportion of crushed sand blending results in a gradual reduction in both the water absorption rate of the mixed sand and the quantity of water necessary to achieve a consistent degree of slump. This implies that the incorporation of crushed sand contributes to improved workability and hydration characteristics, allowing for the achievement of the desired slump with reduced water content.

2. Conversely, as the grade of the cement concrete decreases and the unit cement dosage is reduced, there is a corresponding increase in the amount of water required to attain the same degree of slump. This trend signifies that, for a given slump target, high-grade concrete exhibits lower unit water consumption compared to its low-grade counterparts. The findings underscore the influence of concrete grade on the efficiency of water utilization, revealing that achieving equivalent workability in higher-grade concrete requires less water than in lower-grade concrete.

4.2 Test Results and Analysis of Each Performance Index of Concrete Mixes

The investigation into the performance of cement concrete prepared by blending natural sand with crushed sand involved a thorough examination of the engineering characteristics of natural sand and crushed sand. This analysis highlighted that the incorporation of an appropriate proportion of crushed sand into natural sand significantly enhances the engineering characteristics of the mixed sand. Key indicators such as crushing resistance, light matter content, water absorption rate, and porosity exhibit improvement. However, it is crucial to strike a balance, as excessively low mix ratios or excessive filler content may hinder the manifestation of these favorable sand characteristics, potentially compromising concrete performance and giving rise to latent engineering issues.

The study delves into a comprehensive examination of various concrete performance indices, including compatibility, slump loss, and compressive strength, across different grades of concrete. Through this multifaceted analysis, the research identifies and proposes the optimal mixing ratios for achieving the desired performance attributes. The findings contribute valuable insights into the nuanced interplay between natural and crushed sands, providing practical guidance for achieving optimal concrete mix compositions that leverage the enhanced engineering characteristics of blended sands while avoiding potential pitfalls associated with improper ratios. This in-depth exploration of performance indices aims to inform concrete industry practices and contribute to the broader understanding of sustainable and high-performance concrete formulations.

Table 11 Summary of The Performance Indexes of Concrete with Different Blending Ratios

Test No.	Slump (mm)			Extensibility (mm)			Cohesive Properties		
	Initial	After 1h	After 1h	Initial	After 1h	After 2h	Initial	After 1h	After 2h
C50-1	210	180	160	560	480	450	More viscous	More viscous	Normal
C50-2	210	200	170	580	500	470	Good	Good	Normal
C50-3	210	200	190	600	520	500	Good	Good	Good
C50-4	210	200	190	610	530	500	Good	Good	Good
C50-5	210	200	180	600	530	480	Good	Good	Good
C50-6	210	200	170	600	520	440	Good	Good	Good
C50-7	210	200	170	560	500	440	Good	Good	Good
C20-1	200	180	150	540	470	400	Good	Good	Normal
C20-2	200	180	150	530	470	400	Good	Good	Normal
C20-3	200	170	130	530	450	390	Good	Normal	Normal
C20-4	200	140	100	510	440	—	Good	Normal	Bad
C20-5	200	160	80	430	—	—	Good	Normal	Bad
C20-6	200	130	50	400	—	—	Good	Worse	Worst
C20-7	200	80	20	350	—	—	Good	Bad	Worst

Table 12 Summary of Performance Indexes of Concrete with Different Blending Ratios

Test No.	Separation Situation			Air Content (%)			Water Secretion	Compressive Strength (MPa)	
	Initial	After 1h	Initial	Initial	After 1h	After 2h	None	7d	28d
C50-1	None	None	None	4.4	3.5	2.7	None	—	63.7
C50-2	None	None	None	4.7	4.0	3.2	None	—	61.5
C50-3	None	None	None	5.1	4.3	3.5	None	—	59.9
C50-4	None	None	None	5.5	4.6	3.7	None	—	58.2
C50-5	None	None	None	5.9	5.0	3.8	None	—	56.6
C50-6	None	None	None	6.2	5.2	4.0	None	—	55.0
C50-7	None	None	None	6.5	5.3	4.0	None	—	52.3
C20-1	None	None	Slight	3.7	3.0	2.2	Slight	—	34.3
C20-2	None	None	None	4.4	3.5	2.7	None	—	31.2
C20-3	None	None	None	4.9	3.9	3.1	None	—	28.7
C20-4	None	Slight	None	5.5	4.5	3.2	None	—	25.6
C20-5	None	Slight	None	5.8	4.9	3.6	None	—	24.7
C20-6	None	Slight	Slight	6.5	5.5	4.0	None	—	22.6
C20-7	None	Slight	Slight	7.0	6.0	4.7	None	—	17.2

The examination of Tables 11 and 12 yields several insightful conclusions regarding the performance indices of concrete mixes in the study on the performance of cement concrete prepared by blending natural sand with crushed sand:

1. Air Content Dynamics Over Time:

The air content of concrete exhibits a gradual decrease over time. Notably, for concrete of the same grade, higher quantities of natural sand admixture result in increased air content. Adhering to the Technical Specification for Highway Bridge Construction on air content (3.5%~5.5%), the determined admixture ratios for C50 and C20 are consistently ≥ 1:1.

2. Compressive Strength and Proportion of Crushed Sand:

The compressive strength of concrete increases proportionally with the proportion of crushed sand. For C50 and C20 concrete, recommended admixture ratios are consistently ≥ 1:1 and ≥ 2:1, respectively.

3. Optimal Mixing Ratios for Slump Loss:

C50 high standard concrete, with an increase in the proportion of crushed sand, experiences a reduction in slump loss, achieving the optimal effect at a mixing ratio of 2:1 ~ 1:1. In contrast, C20 low-grade concrete exhibits improved slump with an increase in the proportion of sand, reaching the best effect at a recommended ratio of ≥ 2:1.

4. Impact of Natural Sand Blending on Gradation and Fluidity:

The blending of natural sand leads to an improvement in sand gradation and an expansion of concrete, but it also reduces the content of filler particles, affecting concrete fluidity. The best combination of grading and filler content is achieved at blending ratios of 1:1~2:1 for C50 and C20, and 3:1 or pure crushed sand.

5. Cohesiveness in Relation to "Filler" Particles:

Under the same slump circumstance, the cohesiveness of concrete is directly proportional to the content of filler particles. The recommended mixing ratios for concrete C50 and C20 are ≤ 3:1 and ≥ 2:1, respectively, to maintain optimal cohesiveness for on-site activities.

6. Effect of Hydration on Segregation:

With the progression of cement hydration, water absorption by the aggregate, and water evaporation, the free water content in the mixture and air content in the concrete decrease. The volume content of cement paste gradually diminishes, leading to insufficient wrapping of cement paste around the aggregate and potential segregation. For C50 concrete, the large amount of cement and low water-cement ratio ensures adequate cement paste, preventing serious segregation. In contrast, for C20 concrete, the recommended blending ratio is ≥ 2:1, providing sufficient filler particles to enhance segregation resistance in low-grade concrete.

In summary of discussion, the improved workability in concrete blends using mixed sands, as observed in this study, aligns with findings by Nguyen et al. (2022), who noted similar enhancements due to the particle shape and texture of mixed sands. Further, the observed variations in compressive strength at different blending ratios are corroborated by Akhtar et al. (2024), highlighting the impact of aggregate composition on concrete strength. The enhanced durability characteristics of

concrete incorporating mixed sands, as observed in this study, are consistent with the findings of Mundra (2016). Their research also highlights similar improvements in durability when mixed sands are used, reinforcing the validity of this paper results and providing a robust comparison for our experimental outcomes.

4.3 Determination of The Optimal Blending Ratio

The pivotal aspect of the performance of cement concrete prepared by blending natural sand with crushed sand study involves the determination of the optimal blending ratio between natural sand and crushed sand, as highlighted in Table 13.

. This comprehensive analysis incorporates various test performance results, carefully considering factors such as concrete air content, compressive strength, slump loss, sand gradation, fluidity, cohesiveness, and segregation resistance. The established optimal blending ratio not only enhances the engineering characteristics of the mixed sand, including crushing resistance, light matter content, water absorption rate, and porosity but also aligns with or surpasses the stringent requirements outlined in the Technical Specification for Highway Bridge Construction. This critical determination ensures the formulation of concrete mixes that not only meet industry standards but also leverage the synergies between natural and crushed sands to achieve optimal performance and durability in diverse construction applications. The findings contribute valuable insights to the concrete industry, offering a scientifically informed approach to the selection of blending ratios for sustainable and high-performance concrete formulations.

Table 13 Overall Performance of Optimal Blending Ratio

Performance Indicators / Grade of Concrete	Slump	Extensibility	Cohesive Properties	Segregation Situation	Air Content	Compressive Strength	Filler Content	Optimum Ratio of Overall Performance
High-Grade	1:1~2:1	1:1~2:1	≤3:1	—	≥1:1	≥1:1	≤2:1	2:1
Low-Grade	≥2:1	≥3:1	≥2:1	≥2:1	≥1:1	≥2:1	≤ Crushed Sand	3:1

5. Economic comparison of concrete

In the investigation of the performance of cement concrete prepared by blending natural sand with crushed sand, a crucial aspect of the results and discussions focuses on the economic comparison of concrete mixes. To effectively showcase the economic advantages of mixed sand, a meticulous analysis was conducted on the quantities of each material per cubic meter (m^3) of C40 concrete mix ratios constituted with both natural sand and mixed sand (crushed sand: natural sand = 2:1). The summary of material quantities facilitated a detailed cost comparison, taking into account material costs.

The comprehensive findings, as presented in Table 14 reveal a significant cost-saving potential associated with the use of mixed sand in the C40 grade concrete mix. Specifically, the concrete cost for C40 grade concrete can be reduced by 645.48 Birr/m^3 when employing mixed sand instead of natural sand for the mixing design. This translates to a substantial saving of approximately 10% compared to the cost of

concrete prepared with natural sand. This economic analysis not only underscores the financial benefits of incorporating blended sands in concrete production but also provides practical insights for decision-makers in the construction industry, emphasizing the economic viability of adopting mixed sand in concrete formulations.

Table 14 Comparison of Cost of C40 Concrete Configured by Mixed Sand and Natural Sand

Name Of Concrete Material / Comparison Items		Murgher Cement	JD-2 Poly carboxylic Acid Water Reducing Additive	Aggregates (5~14) mm	Aggregates (14~25) mm	Crushed Sand (0~3) mm	Natural Sand (0~5) mm
Unit Price of Each Material		10	110	0.86	0.86	1.01	1.35
Natural Sand Concrete	Mix Design (kg/m^3)	480	7.2	448.2	672.3	0	551.9
	($Birr/m^3$) Cost	7300.70					
Mixed Sand Concrete	Mix Design (kg/m^3)	420	6.15	459.5	689.2	469.3	234.7
	($Birr/m^3$) Cost	6655.22					

The findings of this paper regarding the cost-effectiveness of utilizing mixed sands are corroborated by the economic analysis conducted by Singh and Patel (2023). Their research underscores the potential for cost reductions while maintaining the quality of the concrete, thereby supporting the economic viability of as demonstrated in this study. This alignment with Singh and Patel (2023) conclusions strengthens the argument for the practical application of mixed sands in concrete production.

6. Conclusions

In summary, the research on the performance of cement concrete prepared by blending natural sand with crushed sand underscores the efficacy of blending crushed sand and natural sand in varying proportions. The study successfully formulates concrete with strength grades ranging from C20 to C50, showcasing enhanced workability compared to natural sand concrete, while ensuring that the actual strength fully aligns with design requirements. Next, major findings of the study are presented.

- The blending of crushed sand and natural sand in different proportions proves advantageous, allowing for the formulation of concrete with improved workability for strength grades of C20~C50.
- Optimal mixing ratios are identified for achieving the best working state and compressive strength at 28 days. For low-grade concrete (C20~C25), a mixing ratio of 3:1 (crushed sand to natural sand) is recommended, while high-grade concrete (C40~C50) performs optimally at a mixing ratio of 2:1.
- The application of mixed sand in concrete construction yields favorable economic outcomes, exhibiting not only a mitigation of sand supply shortages but also a cost advantage over using natural sand in concrete production. This emphasizes the economic viability and sustainability of incorporating mixed sand in construction projects.

- The synergistic blending of crushed sand and natural sand capitalizes on their respective strengths, creating concrete formulations that strike an optimal balance between workability and strength. This versatility enables the production of concrete mixes tailored to meet the demands of varying construction scenarios, from lower-grade applications (C20~C25) to higher-grade structures (C40~C50).
- Through meticulous experimentation, the study identifies specific mixing ratios that yield superior concrete performance. The 3:1 ratio for low-grade concrete and the 2:1 ratio for high-grade concrete emerge as the most effective blending proportion, showcasing the potential for tailored mix designs to maximize both workability and compressive strength.
- The economic assessment of mixed sand in concrete construction reveals a noteworthy advantage. The application of mixed sand not only addresses the challenges associated with natural sand shortages but also proves to be a cost-effective alternative. This economic benefit, coupled with the ability to mitigate resource scarcity, positions the use of mixed sand as a practical and sustainable choice in contemporary construction practices. The study provides valuable insights for industry professionals, emphasizing the positive implications of adopting mixed sand in concrete construction projects.

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