Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 5508001, 15 pages
https://doi.org/10.1155/2023/5508001

Research Article

Performance of Concrete Developed by Enhanced Gradation of Natural Fine River Sands by Partial Replacement of Waste Quarry Dust

Usman Akmal,[1] **Sana Fatima**,[2] **Nauman Khurram**,[1] **Qasim Shaukat Khan**,[1] **Tauqir Ahmed**,[3] **Hisham Alabduljabbar**,[4] **and Youssef Ahmed Awad**[5]

[1]*Department of Civil Engineering, University of Engineering and Technology Lahore, P.O. Box 54890, G.T. Road Baghbanpura, Lahore, Pakistan*
[2]*Bridge Directorate, Punjab Planning and Design Department, Lahore, Pakistan*
[3]*Department of Civil Engineering, National University of Computer and Emerging Sciences (NUCES-FAST), Lahore, Pakistan*
[4]*Department of Civil Engineering, College of Engineering in Al-Kharj, Prince Sattam bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia*
[5]*Structural Engineering Department, Faculty of Engineering and Technology, Future University in Egypt, New Cairo 11835, Egypt*

Correspondence should be addressed to Usman Akmal; usman.akmal@uet.edu.pk

Received 8 July 2022; Revised 22 March 2023; Accepted 11 April 2023; Published 18 April 2023

Academic Editor: Kim Hung Mo

As construction activity continues to increase on a daily basis, the demand for fine and coarse aggregates is also rising. However, relying on a few sources would quickly deplete the natural sources of aggregates. In Lahore, Punjab, Pakistan, costly coarse pit sand from northern areas is used for concrete, as the local river sands (Ravi and Chenab) are fine and do not meet ASTM specifications for fine aggregates. To alleviate the pressure on one source, it is necessary to improve the gradation of natural river sand by utilizing quarry dust obtained during the process of crushing rock into crushed stones. This study conducted detailed experimental work to enhance the gradation of natural river sand by adding normalized quarry dust. Concrete mixes with three strengths of 21 MPa, 28 MPa, and 35 MPa were prepared by partially replacing natural river sand with quarry sand. Workability and hardened concrete properties were evaluated for all mixes, and cost analysis was performed for 28 MPa concrete. The results were compared with control concrete made with coarse pit sand. When river sand was enhanced by combining 40% river sand and 60% normalized quarry dust, the resulting sand met ASTM requirements. Furthermore, when some fines were removed from river sand and replaced with 50% normalized quarry dust, the sand also met ASTM grading requirements. The compressive and flexural strengths of concrete made with enhanced sand gradation increased by 10–25% and 9–17%, respectively, for 28 MPa concrete compared to the control concrete. Cost analysis showed that 28 MPa concrete made with enhanced natural river sand gradation was 8.6% more economical than concrete made with coarse pit sand.

1. Introduction

Concrete comprises Portland cement, water, fine aggregates, and coarse aggregates. About 65 to 75% of the total volume of concrete consists of aggregates [1]. Fine aggregates generally are 35% of total aggregates [2, 3]. The gradation of sand affects the fresh and hardened concrete properties. In the Lahore region, Punjab, Pakistan, sources of natural sands are the "Ravi" river sand and the "Chenab" river sand. The fineness modulus (FM) of Ravi and Chenab river sands do not fall within the range of 2.3 to 3.1 as recommended by ASTM C33 [4]. The pit sand sourced from Attock, Punjab, Pakistan, which satisfies the gradation requirements of ASTM C33 is generally used for concrete. One of the possible solutions is to enhance the gradation of natural river sands using the quarry sand which is obtained as residue from the stone crushing in the quarrying process and consists of particle sizes less than 4.75 mm. The quarry sand is used in roads as surface finishing and filler. It is also used in precast industries to make hollow blocks [5].

The workability of concrete decreases as the quarry sand content is increased. One of the reasons for this decrease is the high amount of fine particles in quarry sand and also the rough texture and angular shape result in more water demand [6]. Durability properties studied indicated that in quarry sand concrete large strains of dry shrinkage at age less than 7 days were observed but they were less at later ages compared with normal concrete [5]. Lower chloride ion penetration and water permeability were reported in the past research work on replacing the natural sand with quarry dust. They also reported at 70% replacement of natural sand with quarry dust, weight due to acid attack, and loss in strength were lowered [7].

The research studies reported that quarry sand could produce concrete with enhanced mechanical and durability properties when partially replaced with sand. Mechanical properties including compressive strength, flexural strength, and split tensile strength for M20 and M25 concretes were studied. It was found that all mechanical properties were maximum at 50% replacement of sand with quarry dust at the age of 7 and 28 days [8]. Compressive strength, split tensile strength, and flexural strength for different replacements of natural sand with quarry dust were evaluated. It was concluded that the mix ratio of 60 : 40 (sand : quarry dust) was optimum [9]. Stress-strain behavior for M25, M30, M35, M40, and M45 concretes by replacing sand at 0%, 25%, and 100% with quarry sand was studied. Maximum modulus of elasticity was obtained at 25% replacement of natural sand with quarry sand [10].

In a study, crushed stone waste was used as a fine aggregate for concrete and compared with the normal concrete. They found that concrete grades M20 and M30 with crushed stone dust gave almost similar compressive strength, flexural strength, split tensile strength, and low shrinkage strains compared to the normal concrete up to 40% replacement of sand with stone waste. They also found that workability was decreased with the addition of crushed stone dust. However, it was improved by adding superplasticizer [11].

The fresh and hardened concrete properties were studied by incorporating crusher dust into the concrete. The study reported that workability decreased when the content of quarry dust is increased. The compressive and flexure strengths were increased when dust content was 10%. Impact resistance was increased for dust content of 5% and decreased with increasing dust content [12].

Omar et al. [13] utilized limestone waste (LSW) as a partial replacement for fine aggregates and marble powder (MP) as an additive. The study found that 28 days compressive strength was increased by about 12% at 50% replacement of sand with LSW. Modulus of rupture was improved by about 8% for 50% LSW and 15% marble powder mix.

Methods to optimize the river sands by incorporating fines of the crusher were evaluated in a study. The study concluded that the compressive strength was increased by about 39% by using optimized sands. Furthermore, mineral constituents determined through X-ray diffraction analysis (XRD) and chemical composition showed that compressive strength was more for sands with higher silica content compared to the ones with higher calcium portions [14].

The use of manufactured sand was also studied in concrete to compare the fresh and hardened concrete properties with control concrete. It was found that using the manufactured sand needs more water/cement (w/c) ratio for workability equal to that of natural sand concrete. This is due to the angular nature of the manufactured sand particles [15]. The modulus of rupture and compressive strength of manufactured sand concrete is more than that of natural sand concrete at the same w/c ratio [16].

The use of recycled fine aggregates as a partial replacement for natural sands was also evaluated by many researchers to conserve the natural resources of sand. It was reported that mechanical properties were reduced by incorporating the recycled fine aggregates as a partial replacement for natural sands. They reported the main reasons for this decrease in mechanical properties are the weak aggregate-matrix interface bond between recycled aggregate and mortar and the higher porosity of recycled aggregate [17–19].

The durability properties of self-compacting concrete were studied by replacing natural aggregates with recycled fine and coarse aggregates. The results showed that with 25% replacement of coarse recycled aggregates had no significant effect on the durability properties of self-compacting concrete including chloride ion and electrical resistivity, while with the increasing fine and coarse recycled aggregates the chloride ion and electrical resistivity decreased. Also, it was found that resistance to chloride ion penetration was significantly reduced with an increase of fine recycled aggregates [20].

In urban areas, there is an increasing demand for infrastructure construction to accommodate the growing population. Concrete is a major material used in infrastructure development and requires sand as an essential component. Currently, coarse pit sand from distant areas is used as fine aggregates in the Punjab region of Pakistan, despite the abundant availability of fine river sands from numerous rivers passing through the area. The fine nature of these river sands has prevented their use in concrete. The transportation cost of pit sand is high, and natural sources are depleting, making it necessary to explore alternatives such as natural river sands to reduce transportation costs and conserve resources. This study aims to evaluate the effectiveness of using fine natural river sands by improving their gradation through the addition of stone quarry dust. This could reduce reliance on far sources of coarse pit sand and transportation costs. The study intends to investigate the workability, compressive and flexural strength, and cost-effectiveness of concrete made with the fine river sands and quarry dust and compares it with concrete made with coarser pit sand. However, the study does not examine the effect of enhanced gradation of fine river sands with quarry dust on high-strength concretes.

2. Experimental Program

2.1. Materials

2.1.1. Cement. Ordinary Portland cement (OPC) having a density of 3.15 g/cm^3 is used in this study. The physical properties of cement are determined and summarized in Table 1.

2.1.2. Aggregates. Fine aggregates were collected from four sources in this study. The first source was Lawrencepur sand (LS) obtained from a pit located in Lawrencepur, Punjab, Pakistan. It has a fineness modulus (FM) equal to 2.15. The second source was the river Ravi sand (RS) located in Lahore, Punjab. The third source was Chenab river sand (CS) from Gujrat, Punjab Pakistan. The FM of RS and CS were 1.12 and 1.26, respectively. The fourth source was the quarry dust generated from the stone crushers having an FM of 2.86. The quarry dust was obtained from the same source from where the coarse aggregates were obtained. The rock type of quarry sand and coarse aggregate is fined grained quartz. RS and CS were used both in original and normalized by partially sieving on sieve #50 (300 μm). Normalized river sands are named normalized Ravi sand (NRS) and normalized Chenab sand (NCS). The quarry dust was normalized by removing particles having a size greater than 4.75 mm and particles having a size lower than 300 μm (fine aggregates passing sieve #4 and retained on sieve #50). The normalized quarry dust is denoted as NC. Pictural views of all sands used in this study are shown in Figure 1. The chemical analysis of cement and three sands (LS, RS, and CS) was conducted according to the ASTM C114 [25] and given in Table 2. The maximum silica content of 92.2% was found in Ravi sand.

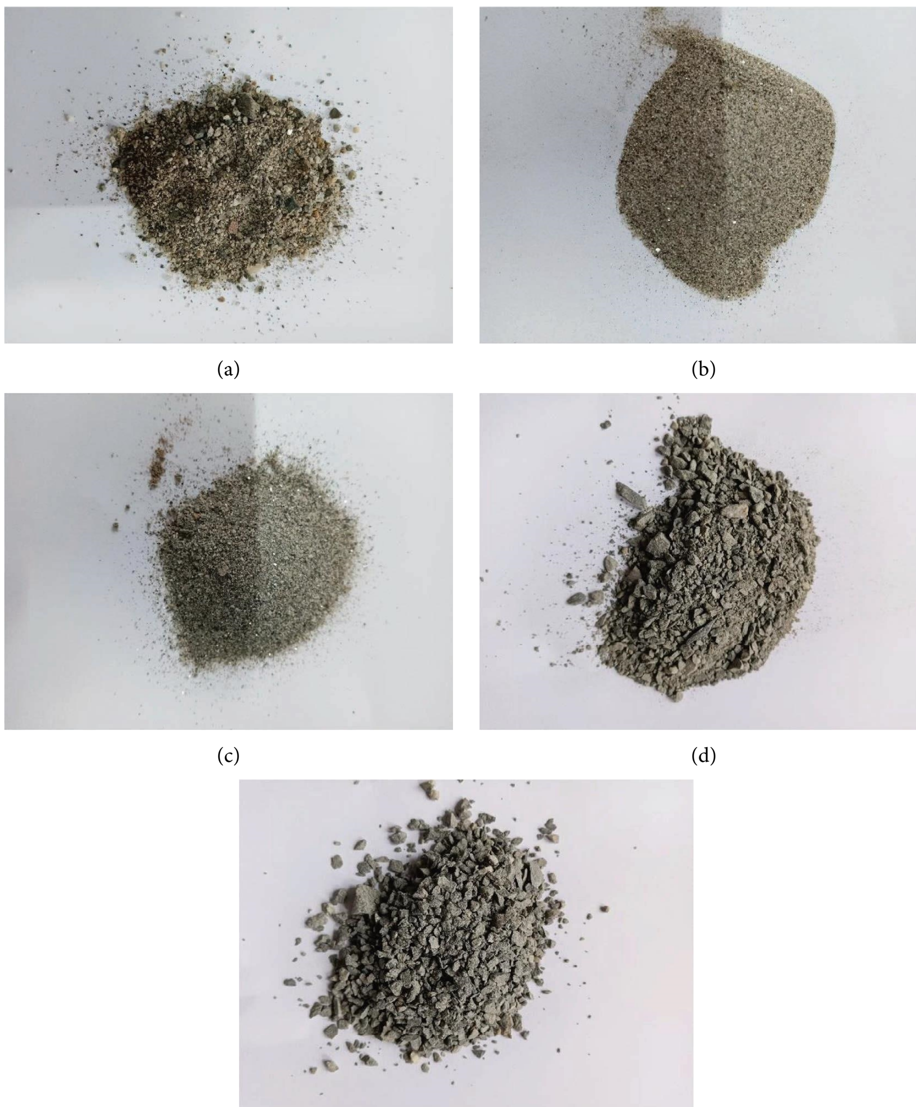
Fineness modulus, rodded bulk density, specific gravity, and water absorption for fine and coarse aggregates are given in Table 3. The FM of quarry dust was 2.86 which were higher than the remaining three sands used in this research. Moreover, FM was increased to 1.61, 1.92, and 3.64 for NRS, NCS, and NC, respectively, after normalizing sands. Gradation curves for fine and coarse aggregates with minimum and maximum limits conforming to ASTM C33 are presented in Figure 2. It is noted that LS and C satisfy the gradation requirements of ASTM C33. To obtain gradation of river sands (RS, NRS, CS, and NCS) that conform to ASTM C33, these are partially replaced with NC (10, 20, 30, 40, 50, and 60%). Gradation curves for all different combinations of river sands and normalized quarry dust are shown in Figure 3. This exhibits that when 40% RS is mixed with 60% NC, then gradation falls within the ASTM limits. Moreover, when 50% NRS is mixed with 50% NC, then the resulting gradation also falls within the ASTM limits. Furthermore, when CS and NCS are partially replaced with NC by 60% and 50%, respectively, the resulting gradation curves fall within ASTM limits as shown in Figures 2(c) and 2(d). For concrete mixtures in which normalized river sand is used in combination with normalized quarry dust, their mix proportion is 50% normalized river sand and 50% NC. On the other hand for concrete mixtures that are using river sands with the addition of NC, their individual content is 40% river sand and 60% NC. The coarse aggregates (CA) sourced from Sargodha, Punjab, Pakistan, with sizes ranging between 4.75 mm and 19 mm was used in the preparation of concrete mixes.

2.2. Mix Proportions. In this research, three concrete types with target compressive strength of 21, 28, and 35 MPa were prepared to investigate the influence of enhanced gradations of river sands on fresh and hardened concrete properties. Mix proportions were determined according to procedure specified by ACI 211.1 [30]. However, more focus is given to 28 MPa concrete as it is generally used for columns, beams, and slabs for four to five stories residential buildings. Three concrete mixes were designed to attain the target compressive strength of 21 and 35 MPa. Whereas, seven concrete mixes were designed to attain a target compressive strength of 28 MPa. For 28 MPa concrete strength, a control mix was prepared using LS followed by three concrete mixes prepared, namely, NRS-NC, RS-NC, and RS. These three concrete mixes were prepared by using normalized Ravi sand and normalized quarry dust, Ravi sand and normalized quarry dust, and Ravi sand only as fine aggregates, respectively. Similarly, for 28 MPa concrete, three concrete mixtures were prepared using Chenab sand, namely, NCS-NC, CS-NC, and CS. These three concrete mixes were prepared using normalized Chenab sand with normalized quarry dust, Chenab sand with normalized quarry dust, and Chenab sand only as fine aggregates, respectively. For each 21 and 35 MPa concrete mixes a control mix was prepared using LS and two concrete mixes were prepared by using Ravi sand only. The two concrete mixes (NRS-NC and RS) were prepared by using normalized Ravi sand and normalized quarry dust, and Ravi sand only as fine aggregates, respectively. The mix details of the 13 concrete mixes are presented in Table 4. Each concrete mix comprised cement, coarse, fine aggregates, and water with varying proportions of different sands in concrete mixes. The water to binder ratios of 0.578, 0.465, and 0.395 were used for 21 MPa, 28 MPa, and 35 MPa concrete, respectively. Same water to binder ratio was used for different mixes of same concrete strength. The quantities of cement, coarse aggregates, and water were kept the same for each target strengths. The quantity of total sand for each mix is also the same for individual concrete strength.

2.3. Specimen Preparation and Curing. Mixing was carried out in a bowl-type mixture. For each mix, cement, coarse aggregates, and fine aggregates were dry mixed for 3-4 minutes. Then, water was added to the dry mix and was mixed for further 2-3 minutes until the desired consistency was achieved. For each mix, six cylinders of 150 mm diameter and 300 mm height were cast to determine the compressive strength as an average of two cylinders of age 7, 14, and 28 days. For each concrete mix, three prism specimens of 100 × 100 × 500 mm were prepared to determine the flexure strength of concrete at 28 days. The cylinders and

Table 1: Physical properties of OPC.

Properties	Standard	Value	Limits
Standard consistency (%)	ASTM C187 [21]	30	—
Initial setting time	ASTM C191 [4]	95 min	≥45 min
Final setting time	ASTM C191 [22]	190 min	≤375 min
3 d mortar cube compressive strength	ASTM C109 [23]	15.7 MPa	≥12 MPa
7 d mortar cube compressive strength	ASTM C109 [23]	24.2 MPa	≥19 MPa
Fineness (passing #200 sieve) (%)	ASTM C204 [24]	93	≥90%



(a) (b) (c) (d) (e)

Figure 1: Pictures of sands used in current study: (a) LP, (b) RS, (c) CS, (d) C, and (e) NC.

Table 2: Chemical analysis of the cement and fine aggregates.

Sand	Element (%)						
	SiO_2	Al_2O_3	CaO	SO_3	Fe_2O_3	MgO	L.O.I*
Cement	21.15	5.12	60.40	2.42	3.22	1.72	3.62
LP	89.40	2.90	2.24	0.051	1.40	0.60	2.64
RS	92.2	2.56	0.84	0.041	1.14	0.90	1.88
CS	91.1	2.25	0.56	0.034	1.34	1.80	2.66
C	62.4	9.52	9.24	0.059	5.43	3.10	9.26

*L.O.I: loss of ignition

Table 3: Physical properties of fine and coarse aggregates.

Material type	Name	Fineness modulus ASTM C136 [26]	Bulk density (kg/m^3) ASTM C29 [27]	Specific gravity ASTM C127 ASTM C128 [28, 29]	Water absorption (%) ASTM C127 ASTM C128 [28, 29]
Lawrencepur sand	LS	2.15	1590	2.67	1.2
Ravi sand	RS	1.12	1470	2.55	1.51
Normalized Ravi sand	NRS	1.61	1400	2.66	1.25
Chenab sand	CS	1.26	1500	2.61	1.3
Normalized Chenab sand	NCS	1.92	1450	2.7	1.22
Quarry dust	C	2.86	1850	—	—
Normalized quarry dust	NC	3.64	1540	2.88	1.35
Coarse aggregate	CA	6.83	1390	2.63	0.88

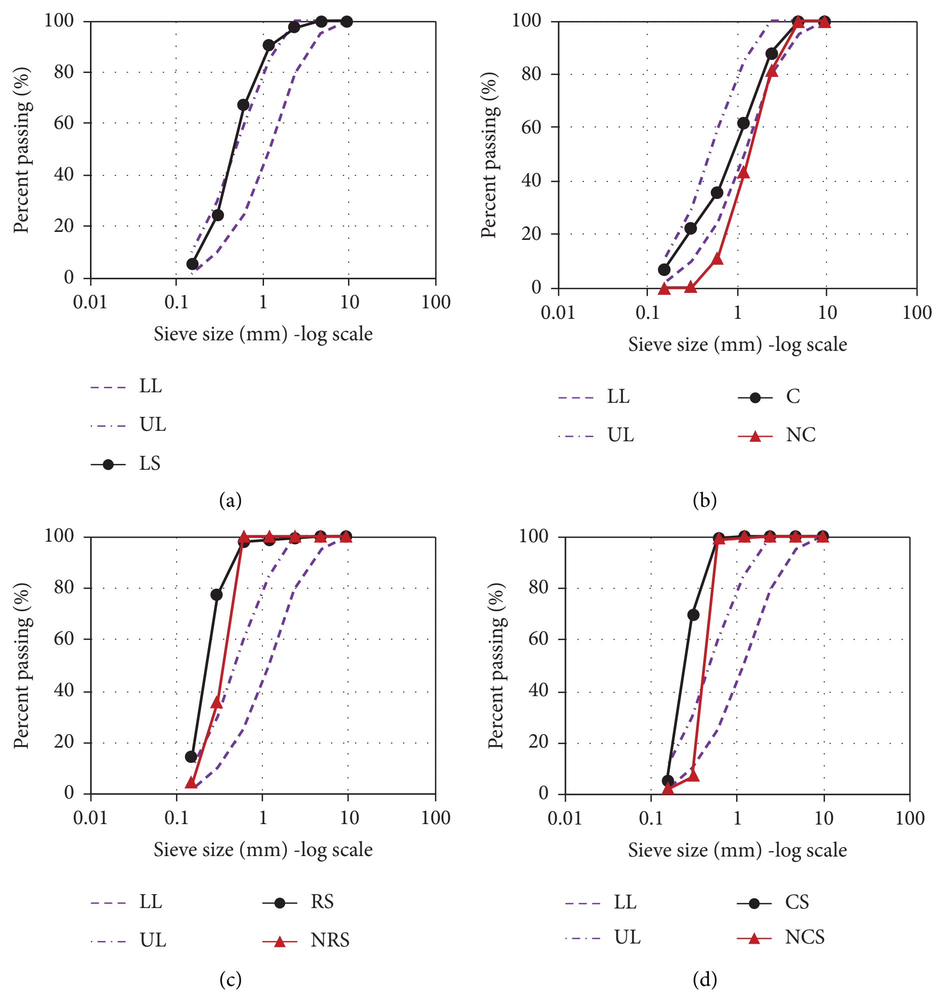
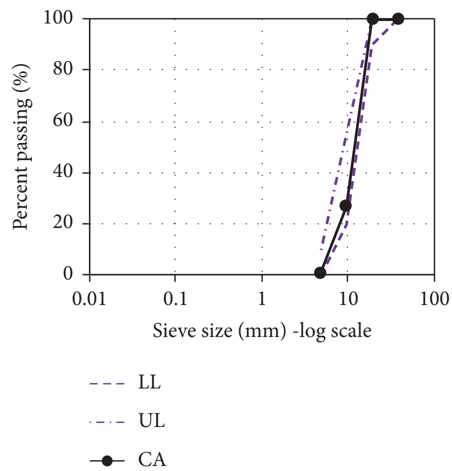


Figure 2: Continued.



(e)

Figure 2: Gradation curves: (a) Lawrencepur sand, (b) Quarry dust, (c) Ravi sand, (d) Chenab sand, and (e) coarse aggregates (LL and UL = ASTM C33 lower limit and upper limit).

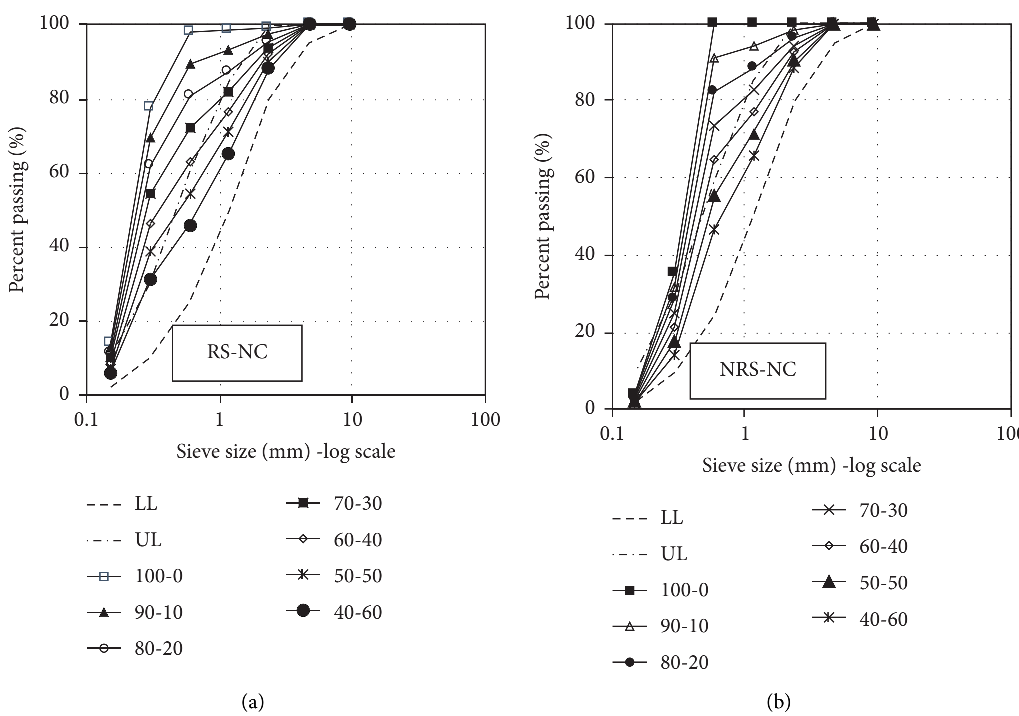
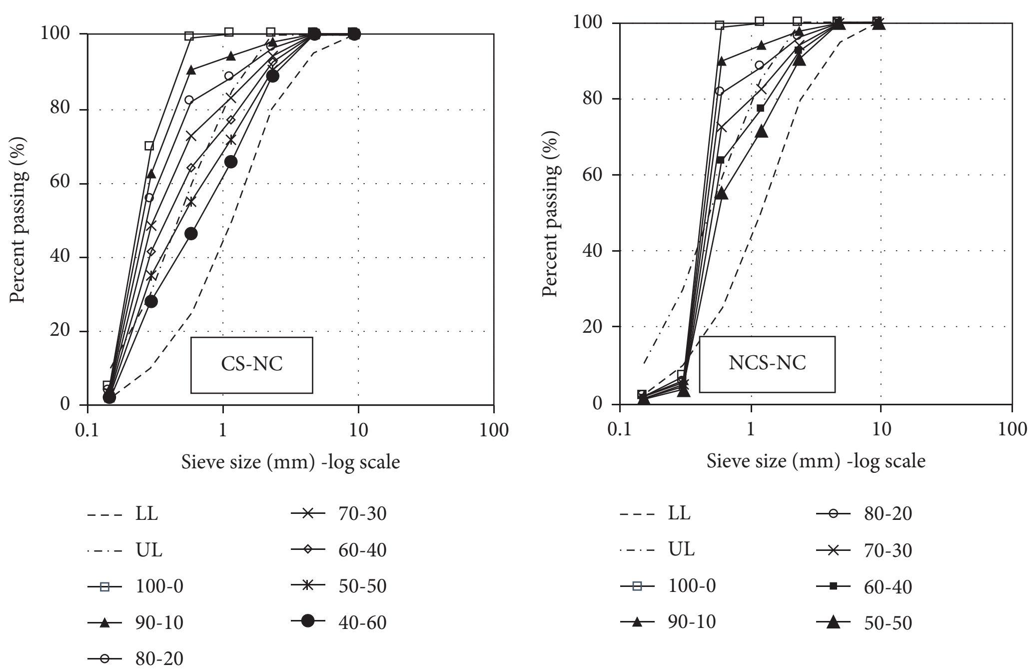


Figure 3: Continued.



(c) (d)

Figure 3: Combined enhanced gradation curves (a) Ravi sand combined with normalized quarry dust, (b) normalized Ravi sand combined with normalized quarry dust, (c) Chenab sand combined with normalized quarry dust, and (d) normalized Chenab sand combined with normalized quarry dust.

Table 4: Mix details.

Conc type	*Mix	W/C	Materials (kg/m^3)								
			Cement	Sand						Gravel	Water
				LS	RS	NRS	CS	NCS	NC		
21 MPa	Control	0.578	346	848	—	—	—	—	—	907	200
	NRS-NC	0.578	346	—	—	424	—	—	424	907	200
	RS	0.578	346	—	848	—	—	—	—	907	200
28 MPa	Control	0.465	450	806	—	—	—	—	—	936	210
	NRS-NC	0.465	450	—	—	403	—	—	403	936	210
	RS-NC	0.465	450	—	322	—	—	—	484	936	210
	RS	0.465	450	—	806	—	—	—	—	936	210
	NCS-NC	0.465	450	—	—	—	—	403	403	936	210
	CS-NC	0.465	450	—	—	—	322	—	484	936	210
	CS	0.465	450	—	—	—	806	—	—	936	210
35 MPa	Control	0.395	506	744	—	—	—	—	—	855	200
	NRS-NC	0.395	506	—	—	372	—	—	372	855	200
	RS	0.395	506	—	744	—	—	—	—	855	200

*NRS: normalized Ravi sand NC normalized quarry dust. RS: original Ravi sand NCS: normalized Chenab sand. CS: original Chenab sand

prisms were filled in three layers and each layer was vibrated using the vibrating table for about 20 seconds. The specimens were demolded after 24 hours of casting and were cured as per ASTM C31 [31] at a room temperature of 23 ± 2°C with wet jute bags.

2.4. Testing of Specimens. The workability of all concrete mixes was measured using slump cone apparatus as per ASTM C143 [32]. Two cylinder specimens for each mix were tested under axial compression in accordance with ASTM C39 [33] at 7, 14, and 28 days of age. Axial compression tests were carried out at platen movement of 1 mm/minute is used. The testing arrangement for axial compression is shown in Figure 4(a). Three prism specimens for each mix were tested under four-point bending to determine the flexural strength of concrete in accordance with ASTM C78 [34] at 28 days of age. All the prisms were tested under platen movement of 0.5 mm per minute. The testing arrangements for four-point bending are shown in Figure 4(b).

(a) (b)

Figure 4: Testing setup: (a) compressive strength test and (b) flexural strength test.

3. Results and Discussions

The effects of enhanced gradation of natural river sands with the addition of normalized quarry dust on the fresh (workability) and hardened (compressive strength and flexural strength) properties of the concrete are presented herein.

3.1. Workability Results. The workability of concrete was measured through the slump test as per ASTM C143. Results of the slump test are presented in Figure 5. Control mixes with LS for all the three concrete compressive strengths of 21, 28, and 35 MPa attain the target slump of 75–100 mm. For 28 MPa concrete, the same slump of control mix was attained with the NRS-NC mix. However, for concrete mixes RS-NC and RS, slump values were decreased by 33.3 and 66.7%, respectively, when compared with the control mix as shown in Figure 5(a). On the other hand, when CS is used for 28 MPa concrete, slump values for the concrete mixes NCS-NC, CS-NC, and CS were decreased by 16%, 33.3%, and 49.3%, respectively, as compared to the control mix as shown in Figure 5(a). For 21 MPa strength concrete, the same slump of 75 mm as of the control mix was attained with the NRS-NC mix. However, the slump value for the concrete mix RS was decreased by 33.3% as compared to the control mix as shown in Figure 5(b). For 35 MPa concrete, slump values for the concrete mix NRS-NC and RS were decreased by 16%, and 49.3%, respectively, as compared to the control mix as shown in Figure 5(c). This general decrease in slump values as compared to control mixes for all the three compressive strength concretes is due to the fact of the high surface area of fine river sands that require more water to produce the same workability as that of the control mix.

3.2. Compressive Strength. Compressive strengths were measured at the age of 7, 14, and 28 days for 21, 28, and 35 MPa concretes and is provided in Figure 6. The rate of gain of strength of all concretes is almost similar. It can be seen from the figure that concrete mixes containing river sands with enhanced gradation using quarry dust (NRS-NC for 21, 35 MPa, and NRS-NC, RS-NC, NCS-NC, and CS-NC for 28 MPa) showed higher strengths at all curing periods than control concrete mix made with LS. The maximum strength of 28 MPa in the concrete mixes was observed in which enhanced gradation was achieved by adding the normalized quarry dust to the original river sand. The reason is a higher quantity of fines from river sands fill the finer pores within the concrete matrix resulting in a more compact and packed structure. In addition to this in all mixes containing quarry dust, the angular sizes of quarry dust resulted in better bonding [35–38]. It is also evident from Figure 6 that the least strength at all curing ages is shown by the concrete mixes in fine aggregates are only comprised of the natural river sands for 21, 28, and 35 MPa strengths. The reason behind this is that a high quantity of fine particles requires more amount of cement paste to coat the larger surface area of fines.

Average compressive strengths at the age of 28 days for 21, 28, and 35 MPa concretes are compared in Figure 7. All compressive strength results with standard deviation are presented in Table 5. It could be observed that for 28 MPa concrete, strength at 28 days for concretes mixes NRS-NC, RS-NC, NCS-NC, and CS-NC are higher by 10.1%, 25.3%, 14.3%, and 25.3%, respectively, than that of control mix incorporating the LS. The reasons for these improvements are the same as discussed earlier in this section. Similar improvements due to the enhanced gradation of river sands by incorporating the quarry dust are observed in the 28 days compressive strength for 21 and 35 MPa concretes as shown in Figures 7(b) and 7(c), respectively. Furthermore, for 21 and 35 MPa concretes made with only incorporating the river sands showed slightly lesser strength than that of control concrete. The possible reason for this decrease is that fine sands required more cement paste and water to coat these particles to show higher strength than that of coarser sand with the same content of cement and less surface area.

3.3. Flexure Strength. The prism specimens of $100 \times 100 \times 500$ mm were cast to determine the flexural strength at the age of 28 days. For each mix, three specimens were cast and tested. The average flexural strengths of 21, 28, and 35 MPa concretes are presented in Figure 8. All modulus of rupture results with standard deviation is presented in

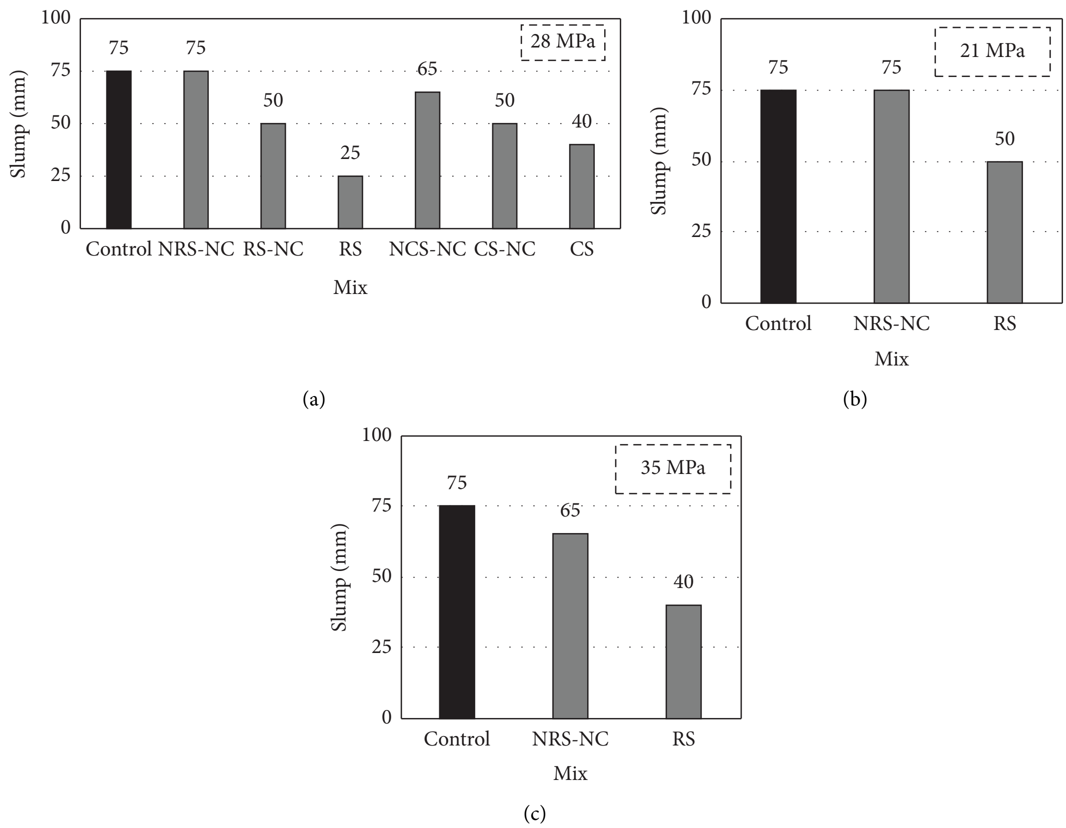


Figure 5: Slump test results: (a) for 28 MPa, (b) for 21 MPa, and (c) for 35 MPa concrete.

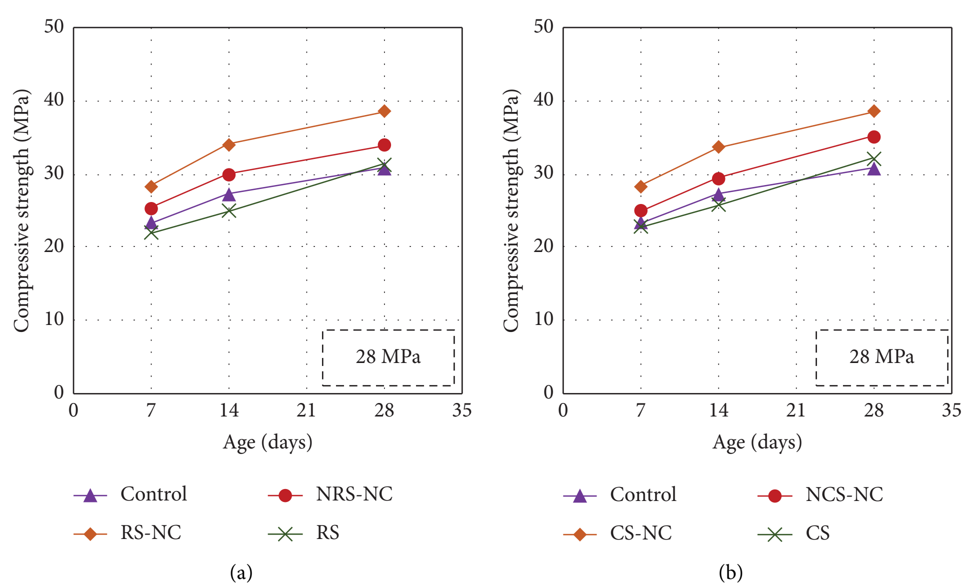


Figure 6: Continued.

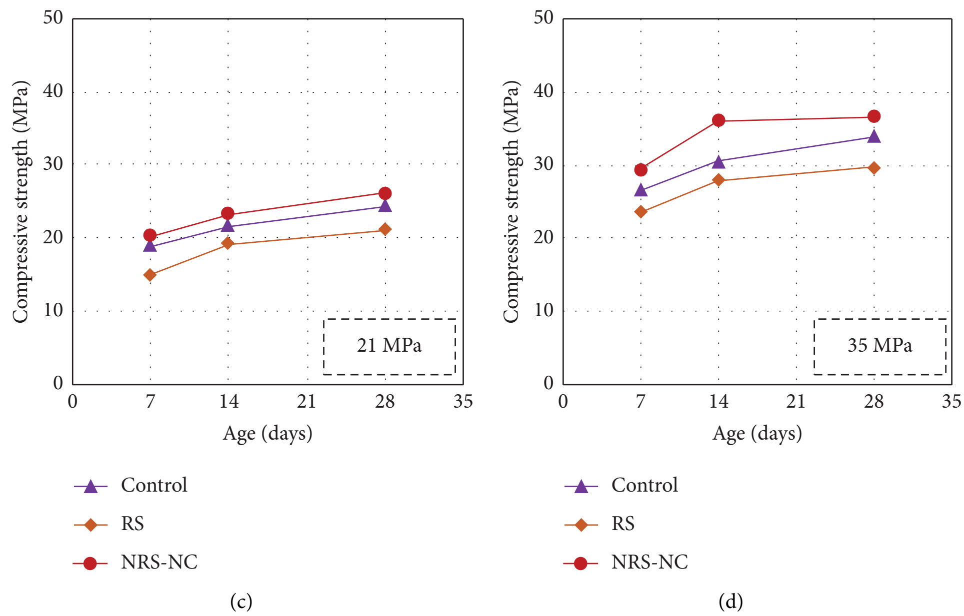


Figure 6: Rate of gain of strength (a) and (b) for 28 MPa, (c) for 21 MPa, (d) for 35 MPa concrete.

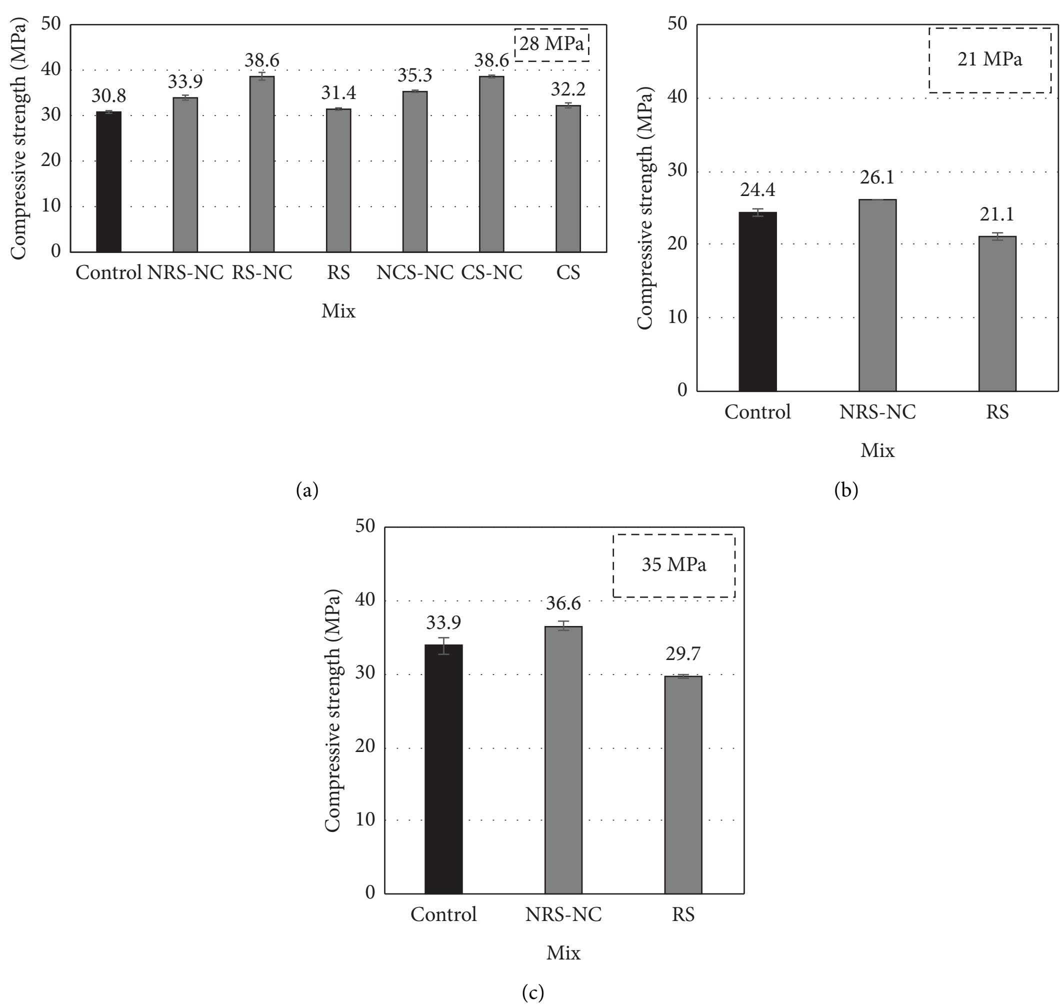


Figure 7: Compressive strength (average) (a) for 28 MPa, (b) for 21 MPa, and (c) for 35 MPa concrete.

Table 5: Compressive strength and modulus of rupture results.

Target strength (MPa)	Mix	Compressive strength (MPa)				Modulus of rupture (MPa)				
		1	2	Avg	SD	1	2	3	Avg	SD
21	Control	23.9	25.0	24.5	0.778	3.60	4.05	3.60	3.75	0.260
	NRS-NC	26.1	26.1	26.1	0.000	4.05	4.30	4.50	4.30	0.225
	RS	20.5	21.6	21.1	0.778	3.15	3.60	3.60	3.45	0.260
28	Control	30.5	31.1	30.8	0.424	4.95	5.15	—	5.05	0.141
	NRS-NC	33.3	34.4	33.9	0.354	5.15	5.85	5.65	5.55	0.361
	RS-NC	39.4	37.7	38.6	1.202	6.10	5.85	6.10	6.00	0.144
	RS	31.1	31.6	31.4	0.354	4.30	4.30	5.15	4.60	0.491
	NCS-NC	35.5	35.0	35.3	0.354	5.85	6.10	5.65	5.85	0.225
	CS-NC	38.9	38.3	38.6	0.424	5.85	6.10	6.30	6.10	0.225
	CS	31.6	32.7	32.2	0.778	4.05	5.40	4.95	4.80	0.687
35	Control	35.0	32.7	33.9	1.626	4.50	5.15	5.15	4.95	0.375
	NRS-NC	36.1	37.2	36.7	0.778	5.40	5.85	5.40	5.55	0.260
	RS	29.4	30.0	29.7	0.424	5.40	4.05	—	4.70	0.955

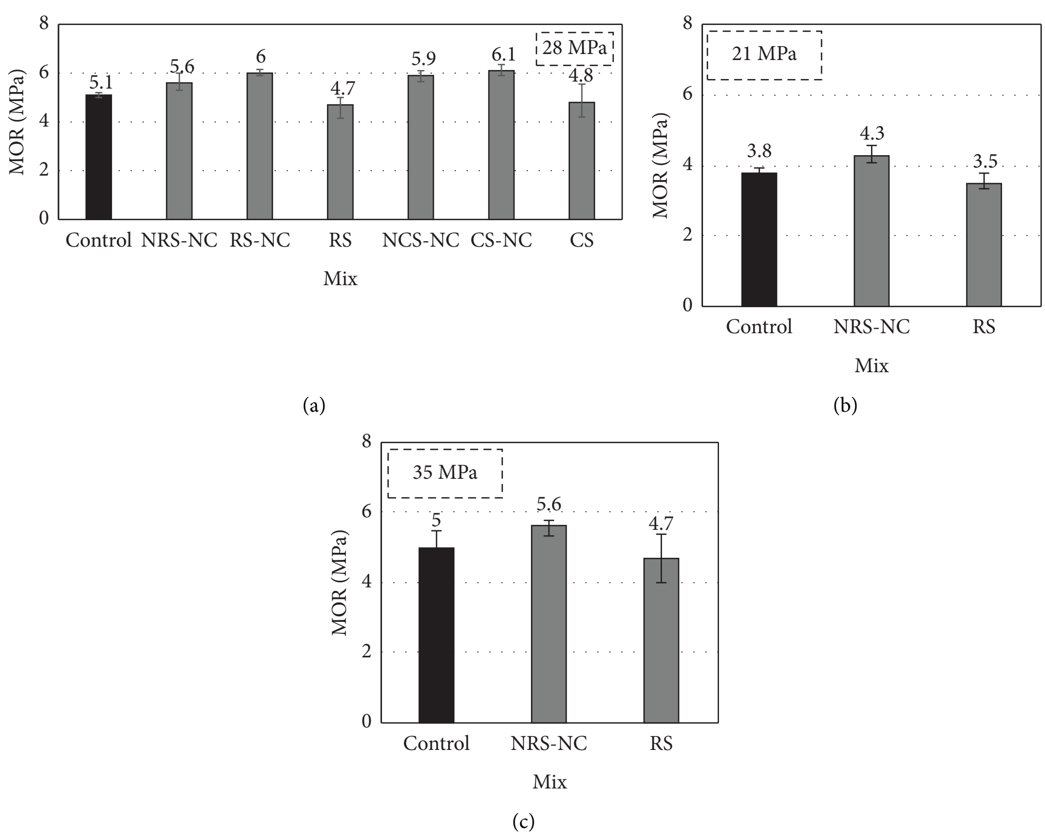


Figure 8: Modulus of rupture (MOR) results (a) for 28 MPa, (b) for 21 MPa, and (c) for 35 MPa concrete.

Table 5. Similar to compressive strength results, it could be observed from Figure 8(a) that for 28 MPa concrete, flexural strength at 28 days for concretes mixes NRS-NC, RS-NC, NCS-NC, and CS-NC are higher by 9.8%, 17.6%, 15.7%, and 19.6%, respectively, than that of control mix incorporating the LS. Similar improvements due to the enhanced gradation of river sands by incorporating the quarry dust are observed in the 28 days compressive strength for 21 and 35 MPa concretes as shown in Figures 8(b) and 8(c), respectively.

An increase of 13.2% by mix NRS-NC for 21 MPa concrete and an increase of 12.0% by mix NRS-NC for 35 MPa concrete in flexural strength is found. Furthermore, for 21 and 35 MPa concretes made with only incorporating the river sands showed slightly lesser strength than that of control concrete. The possible reason for this decrease is that fine sands required more cement paste and water to coat these particles to show higher strength than that of coarser sand with the same content of cement and less surface area.

Table 6: Cost analysis.

Mix type			Control		NRS-NC		RS-NC		RS		NCS-NC		CS-NC		CS	
Material	Units	Unit rate (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)	Qty	Cost (PKR)
Cement	Bags	550	9	4950	9	4950	9	4950	9	4950	9	4950	9	4950	9	4950
Pit sand (LS)	m^3	2295	0.47	1079	—	—	—	—	—	—	—	—	—	—	—	—
Chenab sand (CS)	m^3	1060	—	—	—	—	—	—	—	—	0.24	254	0.2	212	0.5	530
Ravi sand (RS)	m^3	565	—	—	0.26	147	0.21	119	0.54	305	—	—	—	—	—	—
Quarry dust (NC)	m^3	1060	—	—	0.24	254	0.29	307	—	—	0.24	254	0.29	307	—	—
Sargodha crush	m^3	2649	0.69	1828	0.69	1828	0.69	1828	0.69	1828	0.69	1828	0.69	1828	0.69	1828
Total cost (PKR)			7856		7179		7204		7083		7287		7297		7308	
Difference w.r.t control mix (%)			0.0		−8.6		−8.3		−9.8		−7.3		−7.1		−7.0	

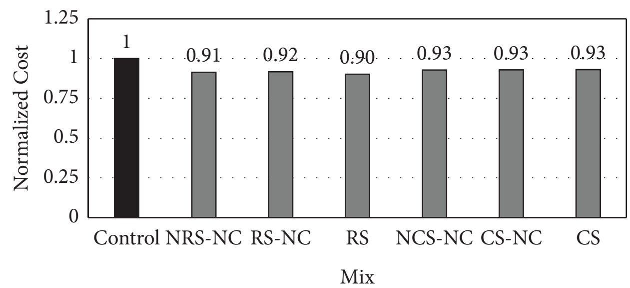


Figure 9: Normalized cost of 28 MPa concrete.

Table 7: Performance indices for 28 MPa concrete.

Property	Mix						
	Control	NRS-NC	RS-NC	RS	NCS-NC	CS-NC	CS
Slump	1.00	1.00	0.67	0.33	0.84	0.67	0.51
Compressive strength	1.00	1.10	1.25	1.02	1.14	1.25	1.05
Modulus of rupture	1.00	1.10	1.18	0.92	1.16	1.20	0.94
Cost	1.00	1.09	1.09	1.11	1.08	1.08	1.07

However, generally improvements in flexural strengths as compared to the control mixes can be due to better bonding achieved by the shape of quarry dust aggregates. The angular particles help in providing better bonding along the crack path developed during the flexural strength test [15].

3.4. Case Study for Cost Analysis. The cost of the ingredients includes material cost, tax, and transportation cost. In addition, the labor, equipment, and overhead charges are the same for all types of concrete mixes. Cost analysis is summarized in Table 6 for all mixes of 28 MPa concrete as a case study for Lahore, Punjab, Pakistan. Normalized cost for all mixes with respect to control concrete is also shown in Figure 9. A mix containing NRS-NC fine aggregates gave the maximum reduction of 8.6% in cost with reference to the control mix with also improved mechanical properties. The reason for this reduction is that Ravi sand RS is obtained from the natural river that has a very less transportation cost. Thus, enhancing the gradation of RS by the addition of quarry dust economical and concrete with better performance than that of control concrete could be achieved.

3.5. Overall Performance Indices. The performance indices of all mixes of 28 MPa concrete are presented in Table 7. Performance indices are calculated as the ratio of better to desirable performance of different indices of mixes. The performance index value greater than 1 for compressive strength, flexural strength, and cost with the enhanced gradation of river sand with the addition of quarry dust showed that concrete obtained by these mixes is economical, as well as has better mechanical properties than that of control mix.

4. Conclusions

In this study, workability and hardened concrete properties including compressive and flexural strength were investigated for 21, 28, and 35 MPa strength concretes by partially adding the quarry dust in fine river sands. The results are compared with that of controlled concrete made by incorporating the coarse pit sand only. The following conclusions are drawn from experimental work carried out in the present work as follows:

(1) The gradation of fine local river sand could be improved by adding 50% of the normalized quarry dust in these sands. The resulting blended sand satisfied the ASTM requirements and improved the physical and mechanical properties.

(2) Concrete mixes prepared by using normalized river sands with the addition of quarry dust showed the same workability as that of the control mix.

(3) Concrete prepared by mixing the river sands and normalized quarry dust increased the compressive strength by 10 to 25% than that of the control mix for 28 MPa concrete. Similarly, for 21 and 35 MPa strength concretes the compressive strengths were improved by 7% and 8%, respectively, than the control concrete.

(4) Flexural strength was increased by 9 to 17%, in the case of 28 MPa concrete mixes prepared by normalized river sands with the addition of quarry dust than the control mix. Similarly, for 21 and 35 MPa strength concretes the flexural strengths were increased by 13% and 12%, respectively, than the control concrete when fine river sands are partially replaced by normalized quarry dust.

(5) The 28 MPa concrete obtained by utilizing enhanced gradation of normalized river sand is 8.6% more economical than the control concrete.

From the discussion carried out previously, the fine natural river sands not satisfying ASTM C-33 grading requirements could be used after enhancing their gradation by adding quarry dust up to 50% by weight to obtain economical and mechanically better concrete than the concrete prepared by utilizing coarse sands from far areas that require high transportation cost. Also, by adopting this methodology of enhancing the gradation of fine natural river sands with the addition of quarry dust the problem of depletion of natural source of the pit sand source could be avoided and local sands could be used for concreting.

Data Availability

All data will be provided if required.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] S. H. Kosmatka and M. L. Wilson, *Design and Control of concrete Mixtures*, Portland Cement Association, Skokie, IL, USA, 15th edition, 2011.

[2] S. Mundra, P. R. Sindhi, V. Chandwani, R. Nagar, and V. Agrawal, "Crushed rock sand – an economical and ecological alternative to natural sand to optimize concrete mix," *Perspectives in Science*, vol. 8, pp. 345–347, 2016.

[3] R. K. K. Chow, S. W. S. Yip, and A. K. H. Kwan, "Processing crushed rock fine to produce manufactured sand for improving overall performance of concrete," *HKIE Transactions*, vol. 20, no. 4, pp. 240–249, Dec. 2013.

[4] Astm C33, *Standard Specification for concrete Aggregates*, ASTM International, West Conshohocken, PA, USA, 2018.

[5] R. Ilangovana, N. Mahendrana, and K. Nagamanib, "Strength and durability properties of concrete containing quarry rock dust as fine aggregate," *International Journal of Science and Research*, vol. 3, no. 5, pp. 20–26, 2008.

[6] S. C. Kou and C. S. Poon, "Properties of concrete prepared with crushed fine stone, furnace bottom ash and fine recycled aggregate as fine aggregates," *Construction and Building Materials*, vol. 23, no. 8, pp. 2877–2886, 2009.

[7] P. M. Shanmugavadivu and R. Malathy, "Durability properties of concrete with natural sand and manufactured sand," in *Proceedings of the International Conference on Science and Engineering*, pp. 368–372, Antalya, Turkey, December, 2011.

[8] G. Balamurugan and P. Perumal, "Behaviour of concrete on the use of quarry dust to replace sand – an experimental study," *International Journal of Engineering Science and Technology*, vol. 3, no. 6, pp. 776–781, 2013.

[9] A. Kannan, K. Subramanian, and A. Aleem, "Optimum mix of quarry dust as partial replacement of fine aggregate in concrete," *International Journal of Engineering Technologies and Management*, vol. 2, no. 5, pp. 1–5, Sep. 2014.

[10] C. K. Kankam, B. K. Meisuh, G. Sossou, and T. K. Buabin, "Stress-strain characteristics of concrete containing quarry rock dust as partial replacement of sand," *Case Studies in Construction Materials*, vol. 7, pp. 66–72, 2017.

[11] A. K. Sahu, S. Kumar, and A. K. Sachan, "Crushed stone waste as fine aggregate for concrete," *Indian Concrete Journal*, vol. 77, no. 1, pp. 845–848, 2003.

[12] T. Celik and K. Marar, "Effects of crushed stone dust on some properties of concrete," *Cement and Concrete Research*, vol. 26, no. 7, pp. 1121–1130, 1996.

[13] O. M. Omar, G. D. Abd Elhameed, M. A. Sherif, and H. A. Mohamadien, "Influence of limestone waste as partial replacement material for sand and marble powder in concrete properties," *HBRC Journal*, vol. 8, no. 3, pp. 193–203, 2012.

[14] G. Sabih, R. A. Tarefder, and S. M. Jamil, "Optimization of gradation and fineness modulus of naturally fine sands for improved performance as fine aggregate in concrete," *Procedia Engineering*, vol. 145, pp. 66–73, 2016.

[15] B. Arulmoly, C. Konthesingha, and A. Nanayakkara, "Effects of blending manufactured sand and offshore sand on rheological, mechanical and durability characterization of lime-cement masonry mortar," *European Journal of Environmental and Civil Engineering*, vol. 26, no. 15, pp. 7400–7426, 2021.

[16] M. Pilegis, D. Gardner, and R. Lark, "An investigation into the use of manufactured sand as a 100% replacement for fine aggregate in concrete," *Materials*, vol. 9, pp. 440–446, 2016.

[17] W. Chen, R. Jin, Y. Xu et al., "Adopting recycled aggregates as sustainable construction materials: a review of the scientific literature," *Construction and Building Materials*, vol. 218, pp. 483–496, 2019.

[18] M. Nedeljković, J. Visser, B. Šavija, S. Valcke, and E. Schlangen, "Use of fine recycled concrete aggregates in concrete: a critical review," *Journal of Building Engineering*, vol. 38, Article ID 102196, 2021.

[19] M. Nili, H. Sasanipour, and F. Aslani, "The effect of fine and coarse recycled aggregates on fresh and mechanical properties of self-compacting concrete," *Materials*, vol. 12, pp. 1120–1127, 2019.

[20] H. Sasanipour and F. Aslani, "Durability properties evaluation of self-compacting concrete prepared with waste fine and coarse recycled concrete aggregates," *Construction and Building Materials*, vol. 236, Article ID 117540, 2020.

[21] Astm C187, *Standard Test Method for Amount of Water Required for normal Consistency of Hydraulic Cement Paste*, ASTM International, West Conshohocken, PA, USA, 2016.

[22] Astm C191, *Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle*, ASTM International, West Conshohocken, PA, USA, 2021.

[23] Astm C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Or [50 Mm] Cube Specimens)*, ASTM International, West Conshohocken, PA, USA, 2021.

[24] Astm C204, *Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus*, ASTM International, West Conshohocken, PA, USA, 2018.

[25] Astm C114, *Standard Test Methods for Chemical Analysis of Hydraulic Cement*, ASTM International, West Conshohocken, PA, USA, 2018.

[26] Astm C136, *Standard Test Method for Sieve Analysis of fine and Coarse Aggregates*, ASTM International, West Conshohocken, PA, USA, 2019.

[27] Astm C29, *Standard Test Method for Bulk Density ('unit Weight') and Voids in Aggregate*, ASTM International, West Conshohocken, PA, USA, 2017.

[28] Astm C127, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*, ASTM International, West Conshohocken, PA, USA, 2015.

[29] Astm C128, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of fine Aggregate*, ASTM International, West Conshohocken, PA, USA, 2015.

[30] ACI 211 1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, ACI Committee 211, Farmington Hills, MI, USA, 1991.

[31] Astm C31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*, ASTM International, West Conshohocken, PA, USA, 2019.

[32] Astm C143, *Standard Test Method for Slump of Hydraulic-Cement concrete*, ASTM International, West Conshohocken, PA, USA, 2015.

[33] Astm C39, *Standard Test Method for Compressive Strength of Cylindrical concrete Specimens*, ASTM International, West Conshohocken, PA, USA, 2021.

[34] Astm C78, *Standard Test Method for Flexural Strength of concrete (Using Simple Beam with Third-point Loading)*, ASTM International, West Conshohocken, PA, USA, 2021.

[35] M. Ali, M. H. Nordin, and S. A. Saad, "Physical and mechanical properties of concrete incorporating manufactured sand," *Advanced Materials Research*, vol. 1115, pp. 160–165, 2015.

[36] B. Arulmoly, C. Konthesingha, and A. Nanayakkara, "Performance evaluation of cement mortar produced with manufactured sand and offshore sand as alternatives for river sand," *Construction and Building Materials*, vol. 297, Article ID 123784, 2021.

[37] H. M. Branavan, K. M. C. Konthesingha, S. M. A. Nanayakkara, and A. Premasiri, "Optimizing blending of manufactured sand with offshore sand based on physical and virtue characteristics. Optimizing blending of manufactured sand with offshore sand based on physical and virtue characteristics," *Journal of Materials Science Research and Reviews*, vol. 6, no. 3, pp. 11–31, 2020.

[38] J. An, S. Kim, B. Nam, S. Durham, and Durham, "Effect of aggregate mineralogy and concrete microstructure on thermal expansion and strength properties of concrete," *Applied Sciences*, vol. 7, no. 12, p. 1307, 2017.