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Comparative Analysis of the Use of Cermin Beach Sand and Deli River Sand as Fine Aggregates on the Compressive Strength of Normal Concrete

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Abstract

River sand is still the main fine aggregate in concrete, while beach sand is abundant along the coast of North Sumatra but rarely used because of concerns about salt and impurities. This study compared the compressive strength of K-250 normal concrete (design f'c 21.7 MPa) made with Cermin Beach sand, washed three times, and with Deli River sand, each used as 100% of the fine aggregate. Mix proportions followed SNI 7394:2008 with a water-cement ratio of 0.56. Both variations used the same Portland composite cement and reached a slump of 12 cm. Three 15 × 30 cm cylinders per variation were tested at 7 and 14 days, and the results were converted to 28-day equivalents using PBI 1971 age factors. The average 28-day equivalent strength was 18.23 MPa (84.0% of the design f'c) for river sand and 11.17 MPa (51.5%) for beach sand, a gap of 6.83 MPa at 7 days and 7.30 MPa at 14 days. Neither variation reached the design strength. Because the 28-day values are estimates, direct 28-day tests, sand characterization, and chloride measurements are recommended before beach sand is considered for structural use.

Keywords: compressive strength, concrete, K-250, beach sand, river sand

Abstract

River sand is still the main fine aggregate in concrete, while beach sand is abundantly available on the coast of North Sumatra but is rarely used due to concerns about salt and impurities. This study compared the compressive strength of normal concrete K-250 (design f'c 21.7 MPa) using Pantai Cermin sand (washed three times) and Sungai Deli sand, each as 100% fine aggregate. The mixture proportion refers to SNI 7394:2008 with a water-cement factor of 0.56, the same composite Portland cement, and a slump of both variations of 12 cm. Three 15 × 30 cm cylinders per variation were tested at 7 and 14 days, then converted to 28 days using the PBI 1971 age factor. The average 28-day equivalent compressive strength was 18.23 MPa (84.0% of the design f'c) for river sand and 11.17 MPa (51.5%) for beach sand, with a difference of 6.83 MPa at 7 days and 7.30 MPa at 14 days. Both variations have not reached the design quality. Since the 28-day age values are estimates, direct 28-day age testing, sand characterization, and chloride content measurement are recommended before beach sand is considered for structural concrete.

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1. Introduction

The construction of buildings, roads, and bridges in Indonesia continues to drive the demand for concrete and, with it, the need for sand. Aggregates constitute approximately 60–75% of the concrete volume, so their properties significantly influence the final result. For fine aggregates, gradation, silt content, grain shape, and water absorption influence water requirements, workability, and ultimately compressive strength [1].

River sand has long been the primary choice due to its relatively stable quality, but excessive extraction causes riverbed erosion, changes in river morphology, and ecosystem damage [2]. Therefore, alternative fine aggregates have been widely studied in the context of sustainable concrete [3], including sea sand which has been reviewed extensively at the international level [4], [5]. In North Sumatra, Cermin Beach sand in Serdang Bedagai Regency is a reasonable candidate due to its large quantity and easy access.

However, beach sand cannot be directly treated like river sand. Chloride salts on the grain surface risk accelerating reinforcement corrosion. A review of seawater-mixed concrete concluded that chloride-rich materials should be used in unreinforced concrete or with non-corrosive reinforcement [6]. Research results in Indonesia are also varied. Dumyati and Manalu reported a compressive strength of river sand concrete of 28.68 MPa, while untreated Sampur beach sand concrete was only 16.36 MPa and increased to 22.14 MPa after the sand was washed [7]. Siswanto et al. obtained 227.41 kg/cm² for beach sand and 260.74 kg/cm² for river sand, and both still met the K-225 quality [8]. Sudirman found that washing one to three times increased the compressive strength, but the results still did not match those of medium-quality concrete [9].

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For the Cermin Beach area, Maulana et al. reported that washed Pondok Permai Beach sand produced 19.55 MPa at 28 days against a design quality of 21.7 MPa, higher than unwashed sand (17.33 MPa) [10]. Studies in Pelabuhan Ratu [11] and comparisons of silica, river, and beach sand [12] both emphasized that the cleanliness, gradation, and origin of the sand determine the results, and Hasan et al. found similar results for Wahede Beach sand [13].

Some of these studies used beach sand in partial substitution or in combination with other materials, such as shells. This study adopted a simpler design: beach sand and river sand were each used 100% as fine aggregate, without additives, with equal cement, water, coarse aggregate, and mix proportions. This way, the difference in results can be directly attributed to the sand source. The research question was how large the difference in compressive strength of K-250 concrete made from Pantai Cermin sand and Sungai Deli sand is, and how close each is to the design quality. The objectives of this article are (1) to determine the compressive strength of both variations at 7 and 14 days along with an estimate of the 28-day equivalent, (2) to compare the two variations and assess them against the f'c of 21.7 MPa, and (3) to discuss factors that might explain the difference and their implications.

2. Research methodology

This study is a laboratory experiment with two variations of fine aggregate, while other factors are kept the same. The independent variable is the type of sand (Deli river sand and Cermin beach sand), the dependent variable is the compressive strength of the concrete, and the control variables include cement, water, coarse aggregate, mix proportion, test specimen size, and curing.

2.1. Materials and Location

Beach sand was taken from the Cermin Beach area, Serdang Bedagai Regency, and washed three times before use. River sand was taken from the Deli River in Delitua District, Deli Serdang Regency. The cement used was composite Portland cement (Semen Padang), coarse aggregate was crushed stone (split), and the water was clean water. Compressive strength testing was conducted at the Concrete Materials Laboratory of the Civil Engineering Study Program, Faculty of Engineering, Islamic University of North Sumatra. The characteristics of the two sands, such as gradation, silt content, and chloride content, were not tested in this study.

2.2. Mixed Planning

The design quality is K-250 (f'c 21.7 MPa) with a design slump of 12 ± 2 cm. The mixture proportion refers to the coefficient of SNI 7394:2008 [14], namely per m³ of concrete 384 kg of cement, 215 liters of water, 692 kg of sand, and 1,039 kg of gravel. From this figure, the water-cement factor is 215/384 = 0.56 and the weight ratio of cement: sand: gravel = 1: 1.80: 2.71. Because the SNI is basically a procedure for calculating the unit price of work, the coefficient is used as the same initial proportion for both variations, not as a design result that adjusts the water content, absorption, and gradation of each sand. The material requirements for one batch (two cylinders, volume 0.0106 m³) are presented in Table 1.

Table 1Mixing Material Requirements (Same for Both Variations)

Material	Per m³ of concrete	Per batch
Composite Portland cement	384 kg	4.07 kg
Water	215 liters	2.28 liters
Sand (river or beach)	692 kg	7.34 kg
Coarse aggregate (split)	1,039 kg	11.01 kg

2.3. Test Objects, Maintenance, and Testing

The test specimens were cylinders with a diameter of 15 cm and a height of 30 cm, three for each variation at each test age (7 and 14 days), so that a total of 12 cylinders. Slump was measured with an Abrams cone [15]. After hardening, the test specimens were removed from the mold and cured by immersion in water until the test age. The compressive strength was tested with a compression testing machine that was loaded gradually until the test specimen was destroyed [16]. The compressive strength of the test results was calculated using Equation (1), with the cross-sectional area from Equation (2).

$$f_c = \frac{P}{A} \tag{1}$$

$$A = \frac{1}{4}\pi d^2 \tag{2}$$

Where f_c is the compressive strength of the test results (MPa), P is the maximum load (N, with 1 ton = 9,807 N), A is the cross-sectional area of the cylinder (mm²), and d is the diameter of the cylinder (150 mm), so that A = 17,662.5 mm².

The design quality is stated at 28 days, while testing is carried out at 7 and 14 days. Therefore, the test results are converted using the concrete age factor according to PBI 1971 [17] as in Equation (3).

$$f'_{c(28)} = \frac{f_c}{k_u} \tag{3}$$

Where $f'_{c(28)}$ is the 28-day equivalent compressive strength (MPa) and k_u is the age conversion factor, which is 0.65 for 7 days, 0.88 for 14 days, and 1.00 for 28 days. The 28-day estimate for each variation is taken from the average of the 7- and 14-day age estimates. This value is an estimate, not a direct 28-day test result. The comparison between the variables is expressed as a difference (MPa) and as a percentage, both against the value of beach sand (as in the thesis) and against the value of river sand.

3. Results and Discussion

3.1. Slump Value

Both mixtures produced a slump of 12 cm, exactly within the design slump of 12 ± 2 cm. This value is above the moderate workability range (25–100 mm), so the mixtures are classified as having high workability. The same slump in both variations means that the resulting difference in compressive strength does not originate from differences in the workability of the mixtures.

3.2. Compressive Strength Test Results

Table 2 summarizes the average values of the three test specimens at each age, and Figure 1 displays the values for each test specimen. River sand concrete was stronger than beach sand concrete at both ages. The compressive strength of river sand increased from 12.215 MPa at 7 days to 15.547 MPa at 14 days, while that of beach sand increased from 7.773 MPa to 9.125 MPa.

Table 2Average Compressive Strength of Test Results and 28-Day Equivalent

Age (days)	Variation	Max. load (tons)	Test compressive strength (MPa)	28-day equivalent (MPa)
7	River sand	22.00	12,215	18.79
7	Sand beach	14.00	7,773	11.96
14	River sand	28.00	15,547	17.67
14	Sand beach	16.43	9,125	10.37

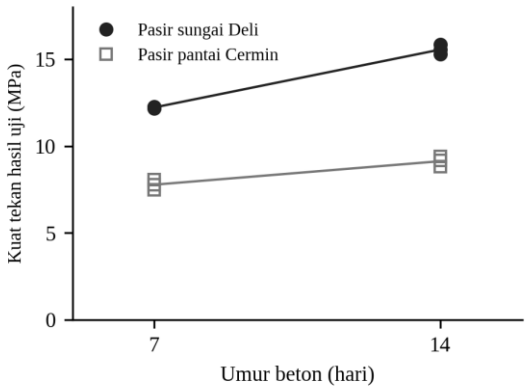


Figure 1Compressive Strength Test Results for Each Test Specimen at 7 and 14 Days (Line: Average)

The distribution of values within each group is small. At 7 days, the three river sand cylinders ranged from 18.71 to 18.88 MPa (equivalent to 28 days), and the beach sand from 11.53 to 12.39 MPa. At 14 days, the ranges were 17.35 to 17.98 MPa and 10.03 to 10.66 MPa, respectively. The lowest values for river sand were always more than 6 MPa higher than the highest values for beach sand at the same age.

3.3. Differences Between Variations and Achievement of Planned Quality

Table 3 shows the difference in 28-day equivalent compressive strength between the two variations. At 7 days, the difference was 6.83 MPa, and at 14 days, it was 7.30 MPa. Compared to beach sand, the differences were 57.11% and 70.40%, respectively. Compared to river sand, the beach sand concrete was 36.3% and 41.3% lower.

Table 3Difference in 28-Day Equivalent Compressive Strength between River Sand and Beach Sand

Basis of comparison	Difference (MPa)	Lower beach sand (%)	River sand is higher (%)
7 days old	6.83	36.3	57.11
14 days old	7.30	41.3	70.40
Average	7.06	38.7	63.2

The average estimated ages of 7 and 14 days give a 28-day equivalent compressive strength of 18.23 MPa for river sand and 11.17 MPa for beach sand (Figure 2). Against the planned f'c of 21.7 MPa, these values are equivalent to 84.0% and 51.5%, with a shortfall of 3.47 MPa and 10.53 MPa. With the same ratio between f'c and K number in SNI 7394:2008, these numbers are approximately equivalent to K-210 for river sand and K-130 for beach sand (author's approximate calculation).

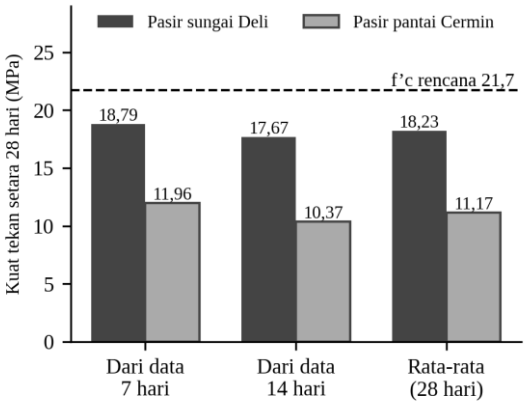


Figure 228-Day Equivalent Compressive Strength against Design Quality f'c 21.7 MPa

3.4. Consistency of Data Differences and Limitations

There are two reasons to believe this difference is not coincidental. First, there is no overlap between the two groups at either age, with the intergroup gap exceeding 6 MPa. Second, the same pattern appears at the two different ages. However, each group consists of only three specimens, so these data are sufficient to demonstrate the direction and magnitude of the difference, but not yet sufficient for a robust statistical test. Because the slumps of both variations are similar, the simplest explanations, such as differences in water requirements or workability, can be ruled out and the

cause must be sought in the sand properties or the procedure.

3.5. The Role of Procedures in Achieving Quality

The failure of river sand to achieve K-250 is noteworthy. River sand is typically used as a reference, but even this concrete only achieved 84.0% of the target, and its highest estimate (18.79 MPa based on 7-day data) was only 86.6%. This suggests that some of the deficiencies stem from the procedure, not the sand. There are three potential causes. First, the SNI 7394:2008 proportions were not corrected for water content and sand absorption. Second, the age conversion factor is general and does not differentiate between cement types, even though the cement used was composite Portland cement. Third, mixing and compaction at small laboratory scales can vary between batches.

The conversion factors also appear to be poorly suited to the observed strength development. The compressive strength of river sand increased approximately 1.27 times from 7 to 14 days and of beach sand approximately 1.17 times, while the PBI 1971 factors assume an increase of $0.88/0.65 \approx 1.35$ times. Consequently, the 28-day estimates from the 14-day data are lower than those from the 7-day data for both variations (Table 2). Because both variations experienced the same conditions, their relative comparison is more reliable than the statement of whether K-250 was achieved. For the second statement, direct testing at 28 days cannot be substituted for conversion.

3.6. Factors That May Explain the Difference

The compressive strength of concrete is determined by the quality of the cement paste and by the bond strength of the paste to the aggregate surface in the interfacial transition zone (*ITZ*), which is generally the weakest part of the concrete [18]. In beach sand, the ITZ can be disturbed by silt, impurities, or unwashed salt residues, while finer gradations change the density of the aggregate.

The beach sand in this study was washed three times and was relatively finer, which, in theory, should help fill voids. However, the results were not close to those of river sand. Washing and fine grading are therefore more accurately described as treatments that support the use of beach sand, not as reasons for its superiority. Grain shape, surface texture, water absorption, fineness modulus, silt content, and chloride content were not tested, so there is no basis for blaming any of these as the direct cause. All that can be said is that the difference is significant and an explanation needs to be sought through testing the sand's characteristics.

3.7. Comparison with Other Research

To ensure the 11.17 MPa figure is not isolated, Table 4 compares the compressive strength ratios of beach sand concrete to river sand concrete in three studies. The comparisons use ratios because the cement, design quality, and test age differed in each study. This study's value is an estimate equivalent to 28 days, while the other studies' values were tested directly at 28 days.

Table 4Compressive Strength Ratio of Beach Sand Concrete to River Sand

Study	Beach sand treatment	Ratio (%)
Dumyati & Manalu [7]	Without treatment	57.0
Dumyati & Manalu [7]	Washed	77.2
Siswanto et al. [8]	Not detailed in source	87.2
This research	Washed three times	61.3

The 61.3% ratio in washed Cermin Beach sand is close to the ratio of untreated Sampur sand (57.0%) and far from that of washed Sampur sand (77.2%). There are two ways to interpret this. Three washes may not have sufficiently reduced the salt and silt, or the underlying cause may not be salt at all, such as gradation or grain shape. Without chloride testing and sieve analysis, both are possible.

Another study in the same area provides important information. Washed Pondok Permai Beach sand reached 19.55 MPa at 28 days against the same design quality of 21.7 MPa [10], or about 90% of the target, well above the 51.5% in this study. That study used direct testing and a larger number of test specimens, and the mixing conditions were not fully comparable. Nevertheless, this difference suggests that the low results here are more likely related to the sand collection point, washing quality, or mixing procedure than to the inherent properties of Cermin Beach sand in general. This hypothesis needs to be tested, not simply accepted.

At the international level, the effect of chloride on sea sand is also managed through binding agents, not just washing. For example, saline sand concrete with fly ash and blast furnace slag showed different performance according to slag content [19], and self-compacting concrete with partial sea sand showed chloride binding in hydration products [20]. This direction can be the subject of further study.

3.8. Practical Implications

These results suggest caution, not rejection. Cermin Beach sand is readily available and accessible, and the concrete produced with simple treatments still achieves around 11 MPa. This may be sufficient for non-structural applications such as work floors, if 28-day testing confirms it. For reinforced concrete, its use should not be recommended until the sand's chloride content is measured, as the risk of reinforcement corrosion cannot be assessed from compressive strength tests alone. Conversely, the river sand's achievement of only 84% of the target is a reminder that mix control,

including correcting moisture content and absorption, is as important as material selection.

3.9. Research Limitations

The above results should be interpreted with five limitations in mind. First, only three specimens were tested per variation at each age. Second, testing was limited to 7 and 14 days, so the 28-day age value is derived from conversion. Third, sand characteristics were not tested. Fourth, the mixture proportions were derived from SNI 7394:2008 coefficients without corrections for water content and absorption. Fifth, the study included only one source of beach sand and one source of river sand, so the results cannot be generalized to the entire Serdang Bedagai coast or all rivers in North Sumatra.

4. Conclusion

At the same mix proportions, cement, and slump, K-250 concrete made from Sungai Deli sand had a higher compressive strength than three-washed Pantai Cermin sand concrete. The 28-day equivalent estimates were 18.23 MPa (84.0% of the design f'c) for river sand and 11.17 MPa (51.5%) for beach sand. The differences were 6.83 MPa at 7 days and 7.30 MPa at 14 days, or approximately 36–41% lower for beach sand concrete, with a consistent pattern. The slump of both variations was the same (12 cm), so the difference did not originate from workability. No variation achieved an f'c of 21.7 MPa, and since the 28-day values were from conversion, achievement of the design quality cannot be stated.

Further research should include direct compressive strength testing at 28 days with more specimens, comprehensive sand characteristics (gradation, fineness modulus, silt content, chloride content, grain shape, and water absorption), tailored mix designs for each sand, and comparisons of washing rates and substitution percentages. Chloride content should be assessed before beach sand is considered for reinforced concrete. Cost and availability are also worth examining to fully assess the suitability of Cermin Beach sand.

Thank-you note

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