PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (4) 1183-1190 April 2025

Compressive Strength Properties Evaluation of Concrete Containing Iron-Laden Spent Sand from Water Treatment Systems and River Sand

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ABSTRACT: Spent sand from water treatment plants has long been a source of environmental concerns due to mineral pollution, notably iron, and environmental degradation. Hence, its use for road pavement construction would be a better option, therefore, the objective of this paper was to investigate the Compressive Strength Properties of Concrete Containing Iron-laden spent sand from Water Treatment Systems and untreated River sand using appropriate standard techniques with concrete cubes of 1:2:4 ratios of sand, cement, and granite. The results showed that after curing for 7 to 28 days, River sand gradually increased in compressive strength, reaching a maximum of 18.9N/mm^2 on day 28, whereas, Spent sand deceased in strength over time, peaking at 12.6N/mm^2 on day 14 and declining to 11.8N/mm^2 by day 28. The River sand consistently outperformed spent sand in both rebound number and compressive strength tests throughout all curing days (7, 14, and 28 days). A pattern was also noticed in the compressive strength of spent sand, which increased from the 7th to the 14th days of curing but decreased by the 28th day for all samples. This revealed that, while spent sand has potential as a construction material, its structural integrity does not compare to that of untreated river sand and should only be used in milder constructions. The researcher also recommended more research on these materials.

DOI: https://dx.doi.org/10.4314/jasem.v29i4.21

Cite this Article as: SIMON, C. E (2025) Compressive Strength Properties Evaluation of Concrete Containing Iron-Laden Spent Sand from Water Treatment Systems and River Sand. *J. Appl. Sci. Environ. Manage.* 29 (4) 1183-1190

Dates: Received: 10 February 2025; Revised: 28 March 2025; Accepted: 09 April 2025; Published: 30 April 2025

Keywords: Spent Sand; Compressive Strength; Water Treatment; Concrete

The escalating volumes of industrial by-products and waste materials have rendered solid waste management a critical environmental issue globally. The limited availability of landfills and their rising costs have made the utilization and recycling of by-products of waste an appealing alternative to disposal. A variety of by-products and waste materials are produced from human activities. The incorporation of such components in construction not only renders it cost-effective but also aids in mitigating disposal issues. The reuse of bulk waste is regarded as the optimal environmental solution for addressing disposal issues. One such industrial by-product is spent sand from water treatment facilities (Alexander *et al.,* 2020). The evaluation of the compressive strength properties of spent sand utilized in water treatment examines the characteristics of spent sand and its prospective applications. This research concentrates on the potential reuse of spent sand derived from water treatment plants, despite its availability from foundries, construction industries, sandblasting, the oil and gas sector, glass manufacturing, recycling facilities, and agriculture as noted by Sharma *et al.* (2019), Smith (2017), and Al-Shammari *et al.* (2017). Spent sand, also known as treatment sand or spent filter sand, is a by-product of

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water treatment procedures which is primarily contaminated with iron and appears brown, making it a possible environmental nuisance by defacing the aesthetics of whatever it comes in contact with. It is often collected at the bottom of sedimentation basins or filter beds in water treatment plants and is rich in numerous minerals and compounds including iron, (Winkler *et al.,* 2020). The compressive strength properties of spent sand is an important characteristic to examine since it influences the sand's ability to support heavy loads and resist deformation under pressure. Compressive strength is a measure of the sand's ability to resist compressive stresses, which is vital for its usage in building, landscaping, and other applications (Bulshakov *et al.,* 2018). By studying the compressive strength property of spent sand, engineers and researchers can create new technologies and methods for recycling and reusing spent sand, minimizing the environmental impact of water treatment operations and supporting sustainable practices in the construction industry. Despite its potential benefits, spent sand is currently underutilized and discarded indiscriminately in the environment or landfills, causing environmental and economic challenges. There is a need thus, to examine its compressive strength property and its qualities to evaluate its potential as a construction material, lowering waste disposal costs and boosting sustainable construction practices (Mahdi *et al*., 2018). Consequently, the objective of this paper was to investigate the Compressive Strength Properties of Concrete Containing Iron-laden spent sand from Water Treatment Systems and untreated River sand.

MATERIALS AND METHODS

Materials

Description of the Study Area: The study was done in the Civil Engineering Laboratory, Federal University Otuoke (FUO), Bayelsa State Nigeria. The Federal University Otuoke (FUO) was established by the Federal government of Nigeria in February 2011, located in Otuoke, a town within the Ogbia local government area of Bayelsa State, Southern Nigeria. The untreated river sand was collected from Otuoke river, while the spent (iron-laden) sand was gotten from a water treatment facility within the Otuoke community and transported to the laboratory.

Sample Collection: Untreated river sand sample was collected with the help of residents (locals) of Otuoke community who were proficient in sand dredging using perforated buckets and canoes. These are people who dive down to the riverbed to get river sand for their daily livelihood, and as such, sand sample was paid for. While the spent sand was gotten from discarded wastes of a water treatment facility within the Otuoke community. Two wheelbarrows of sand each from the two samples was collected and transported to the laboratory. A bag of Dangote cement and an adequate quantity of granite were purchased for this analysis.

Sample Analysis: The following materials were essential for conducting comprehensive testing and analysis to determine the compressive strength and properties of spent sand used for water treatment. The materials were; Spent sand (from water treatment plant), which was the primary material being analyzed. The required quantity was collected from a water treatment plant after being discarded, as shown in figure 1.

Fig 1: The Process of Extraction of Spent Sand from a Water Treatment Plant.

Other materials used were untreated river sand, often referred to as natural sand, composed of silicon dioxide (SiO_2) widely used in construction, manufacturing, and various industrial applications (Liu, 2018). Cement was also used as a binding agent in construction to hold materials like aggregates, sand, and gravel together. It's a fine powder made from limestone, clay, and other minerals, processed at high temperatures. Granite was part of the materials used for this research. It is a coarse-grained igneous rock that is primarily composed of quartz, feldspar, and mica. Water was used primarily to enable the mixing of the other materials. The rebound hammer, also known as a Schmidt hammer, is a tool used to assess the compressive strength of concrete and other materials ((Al-Mansoori, 2018). It works by using a spring-loaded mechanism to strike a surface, and the rebound distance of the hammer is measured. This rebound distance correlates with the hardness and strength of the material being tested. The casting mold, also known as a mold or pattern, was used to create a casted part or product. Casting molds are essential in the preparation of concrete specimens for testing compressive strength. They provide the shape and dimensions required for standardized testing according to industry standards.

Fig 2: Laboratory Procedure Showing Casting Molds (A), Casted Cubes (B) and Curing Tank (B)

Figure 2 above showed the laboratory procedure of active production of concrete cubes with the aid of the casting molds and curing process**.**

Methods: A suitable amount of untreated river sand was collected directly from the riverbed by bucket dredgers in Otuoke community. A suitable amount of untreated spent (iron-laden) sand was also collected directly from the discarded filtration materials of a water treatment plant in Otuoke community. Concrete mix of cement, sand and granite with a mix ratio of 1:2:4 was prepared with the two collected sand samples. Four cubes each of untreated river sand and spent sand were molded and cured for same period (7 – 28 days). Compressive strength of the two categories of cubes was tested using non-destructive technique (rebound hammer), for days 7, 14 and 28 respectively, and results compared.

Test results were collected and analyzed using rebound hammer chart.

RESULTS AND DISCUSSIONS

The results of average rebound test for sampled cubes from river sand and spent sand are presented in table 1 to table 6.

Average Rebound Test: Table 1 below showed the results of average rebound test of river sand cube samples for 7 curing days. The average values of nine (9) points for sample 1A, 2A, 3A, and 4A were 16.333, 15.333, 14.222 and 14.444 respectively.

While Table 2 below showed the result of average rebound test of spent sand cubes for 7 curing days. The average values of nine (9) points for sample 1B, 2B, 3B, and 4B were 12.111, 12.444, 11.333 and 10.666 respectively.

Similarly, Table 3 below showed the results of average rebound test of river sand cubes for 14 curing days. The average values of nine (9) points for sample 1A, 2A, 3A, and 4A were 15.888, 15.888, 16.777 and 16.111. While Table 4 below showed the result of average rebound test of spent sand cubes for 14 curing days. The average values of nine (9) points for sample 1B, 2B, 3B, 4B were 12.333, 12.555, 11.333 and 11.444. Finally, Table 5 below showed the result of average rebound test of river sand cubes for 28 curing days. The average values of nine (9) points for sample 1A, 2A, 3A, and 4A were 18.1, 18.4, 18.6, and 17.2. While Table 6 showed the result of average rebound test of spent sand cubes for 14 curing days. The average values of nine (9) points for sample 1B, 2B, 3B, and 4B were 11.6, 11.5, 11.3 and 10.6 respectively.

Compressive Strength Test: Table 7 and 8 below showed the compressive strength test results (N/mm) of samples of concrete cubes formed from river sand and spent sand according to their respective curing days. The compressive strength test results were gotten after the average rebound test was carried out. The values from the average rebound test were converted to compressive strength using the calibration chart provided by the manufacturers of the rebound hammer. On the chart, it stated that if the mold is cylindrical you multiply the calibration chart value by 1.25, and if the mold is cubic you multiply the calibration chart value by 1.29. Figure 3 to 6 presented graphs illustrating the results comparing the compressive strength of concrete samples molded with river sand (Sample A) and that of spent sand (Sample B), for the three different curing days. Visualizing this data in graphic form allows us to easily identify trends and compare the strength of concrete I relation to time.

Table 1: Average Rebound Test Results of Untreated River sand Sample for Seven Days Curing

Points	Rebound Number Sample (1a)	Rebound Number Sample (2a)	Rebound Number Sample (3a)	Rebound Sample Number (4a)
1	14	15	14	14
2	16	14	14	16
3	19	14	14	14
4	14	15	13	14
5	17	16	16	13
6	17	17	14	16
7	17	17	16	14
8	15	16	14	16
9	18	14	13	15
Average Rebound Number	16.333	15.333	14.222	14.444

Table 2: Average Rebound Test Results of Spent Sand Sample for Seven (7) Days Curing

Points	Rebound Number Sample (1b)	Rebound Number Sample (2b)	Rebound Number Sample (3b)	Rebound Number Sample (4b)
1	14	13	10	10
2	13	14	14	10
3	10	15	10	10
4	10	12	11	15
5	10	12	12	10
6	14	13	10	11
7	14	11	14	10
8	14	10	10	10
9	10	13	11	10
Average Rebound Number	12.11	12.444	11.333	10.666

Table 3: Average Rebound Test Results of Untreated River sand Sample for Fourteen Days (14) curing

Points	Rebound Number Sample (1a)	Rebound Number Sample (2a)	Rebound Number Sample (3a)	Rebound Number Sample (4a)
1	16	16	16	16
2	15	16	16	16
3	15	15	15	18
4	16	16	18	16
5	16	17	18	19
6	15	16	17	16
7	16	16	16	14
8	18	16	16	15
9	16	16	18	16
Average Rebound Number	15.888	15.888	16.777	16.111

Table 4: Average Rebound Test Results of Spent Sand Sample for Fourteen (14) Days Curing

Points	Rebound Number Sample (1b)	Rebound Number Sample (2b)	Rebound Number Sample (3b)	Rebound Number Sample (4b)
1	14	10	10	10
2	15	11	14	10
3	11	14	12	14
4	10	13	12	13
5	12	14	10	12
6	13	14	10	11
7	12	14	12	12
8	13	10	10	10
9	11	13	12	11
Average Rebound Number	12.333	12.555	11.333	11.444

Table 5: Average Rebound Test Results of Untreated River sand Sample for Twenty-Eight (28) Days Curing

Points	**Rebound Number Sample (1a)**	**Rebound Number Sample (2a)**	**Rebound Number Sample (3a)**	**Rebound Number Sample (4a)**
1	20	18	18	16
2	18	21	20	16
3	23	16	20	16
4	20	20	18	17
5	17	18	18	18
6	16	20	18	18
7	16	19	18	20
8	17	18	20	18
9	16	16	18	16
Average Rebound Number	18.1	18.4	18.6	17.2

Table 6: Average Rebound Test Results of Spent Sand Sample for Twenty-Eight (28) Days Curing

Points	**Rebound Number Sample (1b)**	**Rebound Number Sample (2b)**	**Rebound Number Sample (3b)**	**Rebound Number Sample (4b)**
1	15	10	14	10
2	14	14	11	10
3	12	10	10	12
4	10	14	10	10
5	11	10	10	10
6	11	12	10	10
7	12	14	12	12
8	10	10	15	12
9	10	10	10	10
Average Rebound Number	11.6	11.5	11.3	10.6

Table 7 Summary of Compressive Strength Test of Concrete Cubes made from River Sand

Days	**Sample 1A (N/mm^2)**	**Sample 2A (N/mm^2)**	**Sample 3A (N/mm^2)**	**Sample 4A (N/mm^2)**
7	16.6	15.6	14.5	14.7
14	16.5	16.5	17.5	16.4
28	18.4	18.7	18.9	17.5

Table 8: Summary of Compressive Strength Test of Concrete Cubes Made from Spent Sand

Days	**Sample 1B (N/mm^2)**	**Sample 2B (N/mm^2)**	**Sample 3B (N/mm^2)**	**Sample 4B (N/mm^2)**
7	12.3	12.6	11.5	10.8
14	12.5	13.5	11.5	11.6
28	11.8	11.7	11.5	10.7

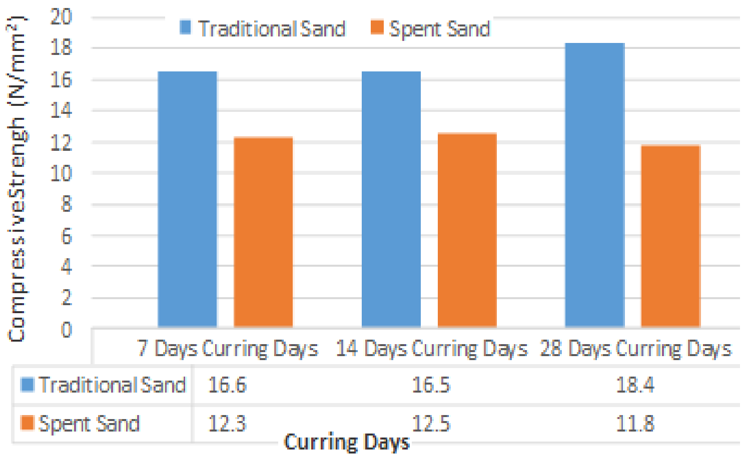

Fig 3: Average Compressive Strength Test of River Sand (1a) and Spent Sand (1b)

The results in Figure 3 showed that the average compressive strength of river sand was higher in all the curing days compared to that of the spent sand. The compressive strength of the river sand ranged from 16.5 – 18.4N/mm^2, with the lowest value at 14 days curing period and highest value at the 28 days curing period. Whereas, the compressive strength of spent sand was lowest during the 28 days curing period.

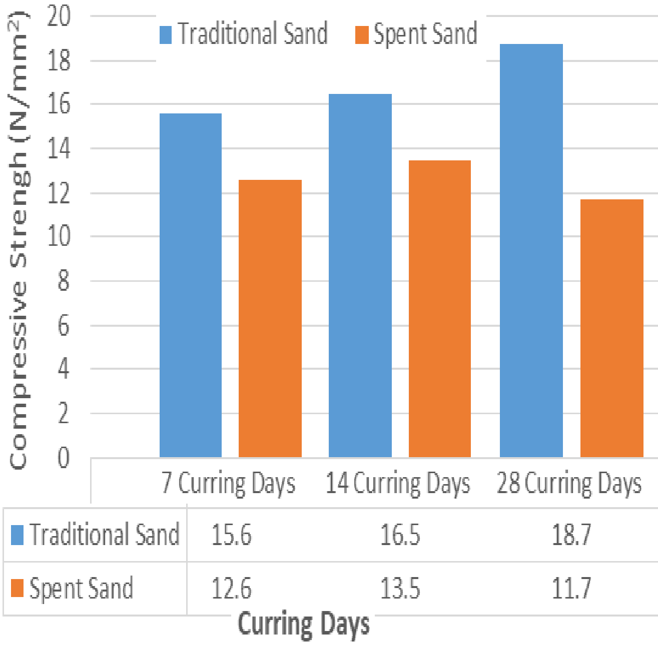

Fig 4: Average Compressive Strength Test of River Sand (2a) and Spent Sand (2b)

The results in Figure 4 showed that the average compressive strength of river sand was increasing progressively from the 7 days curing period to the 28 days curing period (15.6, 16.5, and 18.7N/mm^2 respectively). However, the compressive strength of spent sand decreased with time. That is, it had the lowest value at day 28 and highest value at day 14.

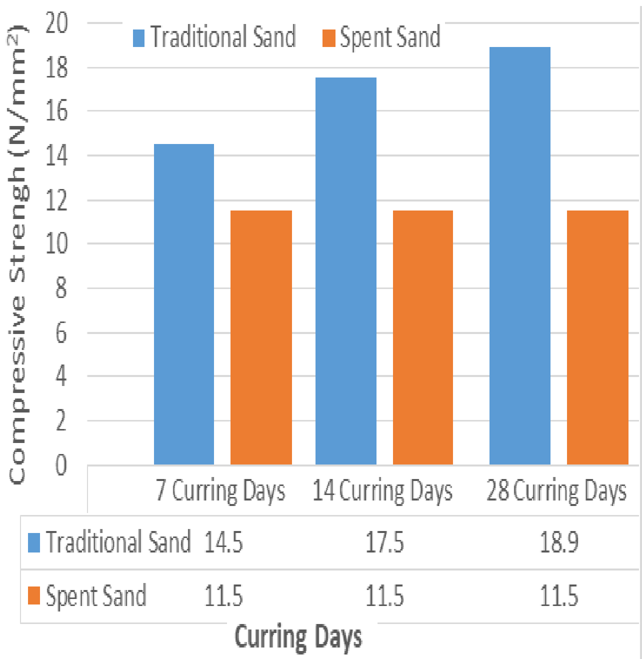

Fig 5: Average Compressive Strength Test of River Sand (3a) and Spent Sand (3b)

The results in Figure 5 showed that the average compressive strength of river sand continued to increase progressively from the 7 days curing period to the 28 days curing period (14.5, 17.5, and 18.9N/mm^2 respectively). However, the compressive strength of spent sand maintained the same averages across all samples, averaging (11.5, 11.5 and 11.5N/mm^2) from the 7 to 28 days curing period.

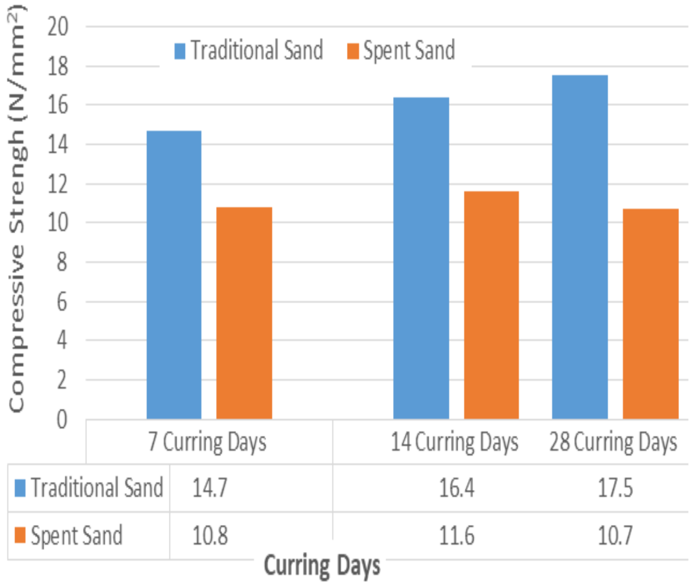

Fig 6: Average Compressive Strength Test of River Sand (4a) and Spent Sand (4b)

The results in Figure 6 showed that the average compressive strength of river sand was increasing progressively from the 7 days curing period to the 28 days curing period (14.7,16.4, and 17.5N/mm^2 respectively). However, the compressive strength of spent continues to decline peaking at 11.6N/mm^2 on day 14, but declined to 10.7N/mm^2 by day 28.

Conclusion: Through rigorous analysis, it was found that the compressive strength of concrete made from spent sand cannot be compared to that of untreated river sand. The findings indicated that the river sand consistently outperformed the spent sand in both rebound number and compressive strength tests across all curing periods (7, 14, and 28 days). A trend was also observed that the compressive strength of spent sand increased from the 7 to the 14 days curing period but reduced at the 28 days curing period for all the samples. River sand showed a gradual increase in compressive strength, reaching a maximum of 18.9 N/mm² on day 28, while spent sand displayed a decline in strength over time, peaking at 12.6 N/mm² on day 14 and dropping to 11.8 N/mm² by day 28. This suggested that while spent sand may have potential as a construction material, its structural integrity does not match that of river sand, and therefore should be only applied to milder constructions.

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