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Sustainable Utilization of Recycled Construction Sand in Structural Concrete: A Mechanical Performance Study

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***Abstract*— With the natural river sand rapidly becoming depleted, and being used in construction industry construction and demolition waste, a swift shift towards sustainable alternatives in the production phase of concrete needs to occur. The potential alternative to virgin fine aggregates will be recycled construction sand (RCS) which is available at Pimpri Chinchwad Municipal Corporation (PCMC) plant at crushing and sieving plant C&D waste. The aim of the research is to experimentally examine the mechanical properties of concrete with the partial substitution of recycled construction sand (RCS) for conventional river sand, focusing on compressive strength, split tensile strength, and flexural strength as the major outcome measures. Natural sand was substituted with RCS (recycled concrete sand) in different proportions to form mixtures of concrete. These samples were left to dry after 28 days under normal conditions and they were examined. The results indicated that an increase in the mixture's composition led to a reduction in the split tensile, flexural, and compressive strengths of the cubes. This decline can be attributed to the angular shape and high absorption qualities of recycled concrete sand (RCS), which weaken aggregate bonding. These findings suggest that using RCS to replace 20–30% of natural sand in structural concrete does not have a detrimental effect on the material's compressive strength. The increasing emphasis on sustainable development, which supports the concepts of recovery and reuse of building waste materials supplied by modern civilization, is the rationale for the introduction of recycled construction sand as a partial replacement of natural fine aggregate in concrete mixes.**

***Index Terms*— Recycled Construction Sand, C & D Waste, Split Tensile Strength, Compressive Strength Flexural Strength, Sustainable Concrete.**

I. INTRODUCTION

Concrete stands as the most widely used material in construction, found just about everywhere. This has made the construction industry the top consumer of natural resources. A big part of concrete is sand, and as cities keep growing and construction picks up, we are burning through natural river sand faster than nature can replace it. It's not a resource we can get back once it's gone.

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Such uncontrolled and random mining of sand along river banks and other water bodies has been leading to numerous negative environmental effects such as river banks erosion and destruction of aquatic life; and groundwater reduction; general destruction of the ecological balance. The fact that sand supply is increasingly controlled by the regulators, and the price of the materials is also going up has necessitated the need to seek alternative materials that are sustainable and can be utilized whenever preparing the concrete. The generation of waste on a mass scale produced out of "C" & "D" Waste has been evident, as the urban centers expand at a terrifying pace, with the old structures needing to be redeveloped and all the new systems laid down. Improperly throwing away this waste in open areas, on roadways and in the water results in pollution and health hazards. So, appropriate gathering and treatment of C&D wastes is significant to generate sustainability in building our centres. Waste management policies by C&D, and systematic collection and monitoring systems results in a supply of material that can be recycled will stay constant and an economy that can afford to sustain the product that has been recycled in the market (1,2).

Recently the Pimpri-Chinchwad Municipal Corporation (PCMC) has also set up several well-organized "C"& "D" waste management systems.

Figure No 1: PCMC C&D Waste Recycling Plant

These include providing the channels of collecting as well as discouraging illegal dumping of C&D wastes by signing contracts with third parties who would sign contracts with PCMC. The practices will also allow the PCMC to deliver processed C&D waste to the contractors that can be re-used to construct materials. Among the abundance of materials is recycled construction sanding material which is produced with the assistance of C&D waste, and nowadays would serve as a substitute of the natural location of river sand, and will save our natural reserves and bring about reduction in the volume of waste generated. However, as the recycled construction sand is sand processed out of stone and concrete, it tends to have a thoroughly differing physical characteristic (i.e. angular particles, large water absorption and mortar adhered) than river sand. The physical characteristics of recycled construction sand can impact the workability, strength and durability of concrete [3]. Although statistical analysis of recycled aggregate has been conducted on a large scale, little has been done to conduct a large-scale mechanical, durability and microstructural analysis of concrete made of recycled sand obtained in municipalities to fully exploit its potential. Thus, this experiment is meant to provide an assessment of mechanical, durability, and microstructural properties of a concrete which partially replaces natural fine aggregate with recycled PCMC demolition garbage construction sand. This will help in establishing processes of developing], and adopting sustainable and green building processes.

A. Research Gap

There is a lot of research on recycled aggregates of a concrete, most of it focuses on coarse recycled aggregates; the use of recycled construction sand (RCS) as a fine aggregate substitute has received less attention. It is not clear the influence of RCS on the long-term durability, structural reliability, mechanical performance other than compressive strength and fresh concrete behavior. Moreover, since it is of variable nature and does not have standardized characterization methods, the structural application of RCS is questionable. The advantages of the environment given above are usually presumed when LCA (life-cycle assessments) is not so widespread. Much of the literature in the recycled aggregates of a concrete concerns coarse aggregates of concrete; the topic of fine aggregates, the practical application of recycled construction sand (RCS) as a fine replacement has received little discussion. The impact of RCS on long-term durability, structural reliability, mechanical performance other than compressive strength and fresh concrete behavior is not clear. Moreover, since it is of variable nature and does not have standardized characterization methods, the structural application of RCS is questionable. It is normally presumed that the above environmental benefits will apply in scenarios where LCA (life-cycle assessments) is not that widespread.

Although much research has been conducted on recycled aggregates in concrete, much of this research has focused on coarse recycled aggregates; little has been done in respect of using recycled construction sand (RCS) as a fine aggregate replacement. It is not known how RCS will influence the long-term durability, structural reliability and behavior of fresh concrete, mechanical performance other than compressive strength. Moreover, due to its unstable features and non- standardized methods of characterization, the structural use of RCS is doubtful. When it comes to environmental gains environmental advantages are supposed, even though there are few cases of inclusive LCA (life-cycle assessments).

B. Novelty

The study is innovative as it combines new, mechanical and durability performance tests to give a systematically based analysis on recycled construction sand in structural concrete. It seeks to quantify long-term structural viability, quantify the benefits of sustainability and develop correlations between material properties and mechanical behaviour. The holistic method helps in formulating performance-based principles to sustainable and safe utilization of recycled construction sand in the structural use.

II. METHODOLOGY

A. Materials

The "natural river sand" used in this study meets the requirements of the control mix of IS 383 and Ordinary Portland Cement meets the requirements of IS 8112/IS 12269 (7). The C&D waste at the Pimpri -Chinchwad Municipal Corporation demolition waste processing facility with coarse aggregate nominal maximum size of 20 mm which are also within the provisions of IS 383 supplied the recycled construction sand (RCS) to produce concrete. The mixing and curing was done using clean, drinkable tap water.

B. Construction Sand Recycled Construction Sand Characterization

The recycled sand had to be characterized as a fine construction sand, and this was tested to ensure the quality of the recycled sand. The distribution of the particle size according to the IS 2386 (Part I) was calculated by sieve analysis. Specific gravity, absorption of water and bulk density were measured according to IS 2386 (Part III). Fineness of the sand and the fines content of the sand was measured and compared with the natural sand.

The results of the tests gave a notion of the differences between the "natural sand" and the "recycled sand" in the aspects of the porosity and the amount of water absorbed [8].

C. Mix Proportions

Natural sand (N.S.) and recycled construction sand (R.C.S.) are used in concrete mixes at six different replacement levels 50%, 20%, 30%, 20%, 10%, and 0 %, respectively. Despite all other mix proportions being guided by the IS 10262 guidelines and ensuring a similar level of workability between mixes, the mix proportion of the control mix is that of 100% N.S. To ensure that the mixes do not share any other mix, the "water" to "cement" ratios (w/c) of each mix category must be equal. To make sure that all the mixes had workability comparable to each other, the chemical additives were not added continuously [9].

D. Concrete Mixing, Curing and Testing Procedures

In order to make sure that the distribution of all components was evenly distributed when preparing concrete a laboratory mixer was used to prepare concrete. A 150mm x 150mm x 150mm cube and 150 mm diameter and 300mm tall cylinders were developed to measure "Flexural Strength", "Split Tensile Strength" and "Compressive Strength" of concrete. All test was casted with plastic sheet to ensure minimum loss of moisture and a remoulding was carried out after 1 day followed by complete curing of all specimens in water at room temperature prior to testing at 28days. The slump test was done on the workability of clean concrete according to 1199 IS; the density of fresh concrete was determined to determine the extent to which recycled fine aggregate influences the density of concrete (10,11).

Compressive strength tests of cube tests were performed as per IS 516; compressive testing apparatus was then loaded at rates which were controlled. Redundance revision of the modulus of rupture of individual beams was the maximum weight on the beam, which was broken; split tensile strength was calculated on cylindrical specimen in accordance with the IS 5816; flexural strength was calculated on beam specimens in the two point load procedure of the IS 516. The water absorption and Capillary assays were done in order to identify the performance of durability. The mass of the "oven-dried" and "water-saturated" specimens less is known as the water absorption and the rate at which the capillary water is absorbed with time is referred to as sorptivity. The bulk density of computed to determine the compactness and pore structure of the different concrete mixes

Figure 2: Casting of concrete cubes to be embarked on mechanical testing using recycled Sand.

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III. Result and Discussion

A. Compressive Strength Results

The "Compressive Strength" at 28 days of various mix designs joined on concrete with recycled sand as an aggregate formed the basis of a "long-term performance" assessment of the concrete. Three cube specimens of the different mix designs after 28 days were subjected to compressive strength, as per IS 516 standards. The average value was used to analyze these tests.
The table below lists the compressive strengths for each sample, along with the strengths of mixtures where recycled sand replaced natural sand at levels from 0% up to 50%.

Table I: Results of Compressive Strength Curing Ages

Mix ID	Sand Recycled (%)	Test-1	Test-2	Test-3	Total Average
M0	0%	41	41.3	41.2	41.2
M10	10%	40.3	40.7	40.5	40.5
M20	20%	41.9	40.5	41.6	41.3
M30	30%	39.3	39.8	39.5	39.5
M40	40%	36.9	37.5	37.2	37.2
M50	50%	34.2	33..8	34	34

This evaluation shows the reaction and interaction of the different materials in the wake of the standard curing time (28 days) by comparing the strengths of concrete with the strengths of partially substituted natural river sand, in the light of the certain sand material used during the conventional phase (28 days). Compressive strength is important. Talking of strength what happens is that the greater the amount of recycled sand that we take the less compressive strength we possess. This is what we see when we look at the results of strength, at different times after the concrete has been made. The lower the "Compressive Strength" results are the lower the recycled sand we use. This is one of the trends which we feel. An example was concrete mixes containing 20-30 per cent of recycles sand had compressive strengths that matched those of concrete mixes containing natural river sand (control mix).

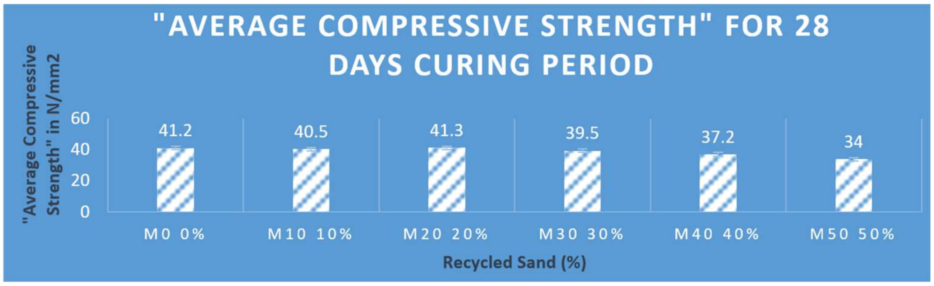

Figure 3: Correlation between "Compressive Strength of the Concrete" and the substitution of "Fine Aggregates" with the recycled ones.

Once the sand which is recycled is below 30 percent of the "Concrete Strength" is declining at an escalated rate. That is why the concrete with and without sand is not as strong as it would have been with sand, but the sand particles that have been recycled contain more holes as well as absorbing more water. This has an influence on the concrete and the region at which the concrete is in contact with the material in which it is embedded. The problem with the recycled sand is that the sand is very porous, and retains the surplus water that alters the concrete. The same cannot be said with the concrete containing sand because of the recycled sand.

B. Split Tensile Strength

At 28 days of curing, we test the split tensile strength of concrete mixed with construction sand. This tells us how swapping some of the natural fine aggregate for recycled sand affects the concrete's ability to handle tension. By testing the concrete after 28 days, we get a clear idea of what recycled construction sand actually does to tensile strength when it replaces part of the fine aggregate. After producing the concrete and letting it cure, we record the split tensile strength, focusing on how recycled sand changes the result compared to using only natural sand. The goal is simple: see if using recycled construction sand—at least for some of the fine aggregate—makes a real difference in tensile strength (12).

Overall, three cylindrically shaped specimens were produced and tested as per IS 5816 in relation to each of the various proportions of concrete to ensure credible results were achieved. Individual specimen and composite split tensile strength of all the levels of recycled sand replacement (0-per cent - 50 per cent) are shown in table 2 below.

TABLE II: OVERALL SUMMARY OF "SPLIT TENSILE STRENGTH" TEST RESULTS OF "RECYCLED FINE AGGREGATE CONCRETE"

Mix ID	Sand Recycled (%)	Test-1	Test-2	Test-3	Total Average
M0	0%	3.85	3.95	3.9	3.9
M10	10%	4.15	3.95	3.9	4
M20	20%	3.65	3.75	3.7	3.7
M30	30%	3.45	3.55	3.5	3.5
M40	40%	3.25	3.35	3.3	3.3
M50	50%	2.95	3.05	3	3

This test assesses the effectiveness of the tensile strength variation with the amount of sand recycled and assists in comprehending the effectiveness of each concrete mix in terms of its resistance to cracking

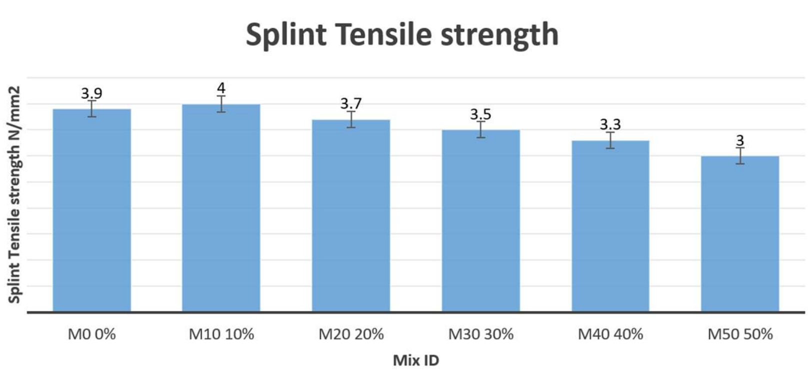

Figure 4: The impact of the content of recycled fine aggregate on split tensile strength at 28 days

The results indicate that the “strength of the concrete” mix split tensile strength will be equal to the “control mix strength” when the percentage of sand that is recycles in the concrete mix is less than 10 per cent but the split-tensile strength will continue to reduce as the recycles sand percentage in the concrete mix increase beyond 10 per cent. The decreases in the tensile strength at the elevated percentages could be attributed to the fact that the extra porosity and lower interfacial transition zone related to the sand particles that are recycled are influencing the concrete performance.

C. Bending strength of concrete

They have experimented to find out the impact of using recycled sand on the strength of concrete when bending. The aim of the experiment was to establish the effects of strength of concrete that is recycled using recycled sand. They would like to know whether the sand that is recycled causes the concrete to be stronger or weaker upon bending. The experiment will comprise proportional mixing of sand found naturally within the environment with a replacement of sand with a one percent (0, 10, 20, 30, 40 and 50) percent amounts of recycles aggregates (sand and gravel). The ratio was experimented at three samples and the statistics of their flexural strength scanned (13). Then, the “Average Compressive Strength” of each mixture was calculated; This allowed observing the impacts of recycled material on the concrete performance. The test indicated how the concrete will be improved by adding the recycled materials in it. The more recycled materials which are incorporated into the concrete the better the concrete will perform

TABLE III: EFFECT OF “RECYCLED FINE AGGREGATE” CONTENT ON “FLEXURAL STRENGTH OF CONCRETE”

Mix ID	Sand Recycled (%)	Test-1	Test-2	Test-3	Total Average
M0	0%	5.8	6	5.9	5.9
M10	10%	5.9	5.95	5.95	5.93
M20	20%	5.7	5.6	5.7	5.7
M30	30%	5.1	5.3	5.2	5.2
M40	40%	4.8	5	4.9	4.9
M50	50%	4.5	4.7	4.6	4.6

The records indicate that content of recycled sand that reduces the “Compressive Strength of Concrete” slurry increases gradually. The “Control Mix (M0)” has the best “Average Strength of 5.9 N/mm2” and the recycled sand percentage is zero. The blend that contains 50% recycled sand replacement (M50) has the lowest average strength at 4.6 N/mm 2

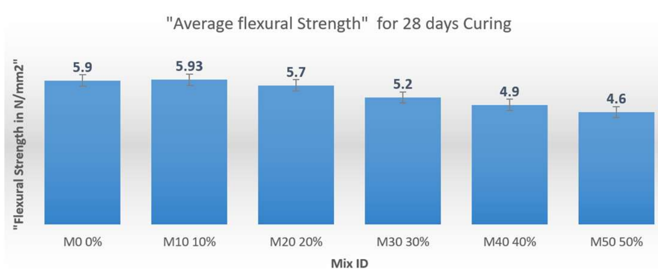

Figure 5: Nurturing of flexural strength of recycled fine aggregate concrete.

The implication of this is that the more we recycle the sand; the lower will be the “Compressive Strength” of the concrete; this is due to the difference in shapes and texture of the particles, and differences in absorption properties of the recycled sand versus natural sand. Other studies on recycled aggregates have found the same results; however, these findings suggest that there is potential for recycled sand to be used in concrete, but require careful consideration in the design of concrete mixes.

D. Discussion

Using recyclable construction sand (RCS) instead of natural river sand really changes how concrete behaves—its strength, how long it lasts, and even what it looks like up close. Testing shows that RCS does seem like a pretty eco-friendly choice, which is a big plus. Every time RCS replaces regular sand, the concrete tends to lose some compressive strength. Why? Mostly because the recycled sand soaks up more water and the grains come in all sorts of shapes and sizes. That messes with how easy the concrete is to mix and pour, and it makes the bond between the sand and the rest of the concrete weaker. So, while RCS is promising for the planet, there’s a clear trade-off in strength that builders need to consider carefully.

This was primarily due to augmented intake of water by the recycled sand material coupled with inhomogeneous character of the shapes of the particles which minimized both the workability and the interfacial transition zone which was found amid the aggregate. The use of recyclable construction sand (RCS) as an alternative to natural river sand greatly affects the mechanical, durability and microstructural concrete performance. The findings of the experiment show that although RCS may be deemed as a sustainable substitute to virgin sand since it imposes an insignificant environmental impact, its performance greatly depends on the nature of the chemical and physical characteristics of the material used and the amount of used RCS compared to the normal sand. The concrete mixtures that were made by use of RCS experienced a consistent compression strength reduction as compared to those that were mixed by use of control mixtures. This was primarily due to the greater water uptake and atypical particle shapes of the recycled sand material that lowered workability and interfacial transition zone that was formed amongst the aggregate. However, when replacing with lower replacement rates (approximately up to 20-30 percent); there was only a slight loss of strength indicating that RCS can be partially applied without significantly reducing the quality of the concrete mix. The same trends were observed in both tensile strength flexural strength and split. This justifies the importance of inter-locking and bonding using the particles to resist tensile and bending stresses between the particles, which led to the decrease in ductility with higher RCS content, and so, a delicate proportioning of the mix or the use of additional cementitious material to enhance the bond between the particles would be necessary to obtain proper performance (14,15). In addition, the replacement of natural sand with RCS has many sustainability benefits such as reduction of the necessity to use river sand, reduction of the number of wastes produced during construction projects, reduction of the carbon footprint of concrete production. In addition, RCS is a cheaper alternative to natural sand in urban areas where the waste typically consists of construction and demolition waste. Even with a slight decrease in mechanical and durability performance, proper mixes, and use of SCMs can eliminate the negative impacts of involving RCS as a viable and environmentally-friendly material in making concrete during the present-day construction.

IV. CONCLUSION

The findings of the research indicate that recycled construction sand (RCS) can be used to partially replace natural river sand in concrete and help to promote environmentally friendly construction processes and protect natural resources. This experiment establishes “Flexural Strength”, “Compressive Strength” and “Split Tensile Strength” of a concrete that is prepared with a varying percentage of RCS. In all three kinds of mechanical property, there was a small decrease in the rise in the percentage of RCS. The recycled sand materials' increased porosity and irregular shapes, which decrease workability and, consequently, the aggregate–paste bond, are the primary causes of the decreased strength characteristics. But even 20-30% replacement of sand by RCS will result in concrete with little loss of mechanical strength i.e. still within reasonable structural concrete specifications. The results therefore indicate that RCS can surely be used as an alternative in controlled levels with no significant reduction in the mechanical performance. When well planned to maximize the concrete mix, recycled construction sand will offer a viable, cost-efficient and eco-friendly alternative to natural river sand that is required to be used in the production of concrete.

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