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Effect of Crushed Concrete as a Replacement for Fine and Coarse Aggregate in the Production of Concrete

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ABSTRACT

This paper assesses preliminary attempts at using Recycled Concrete Aggregates (RCA) to substitute for the natural aggregates used in concrete production with different percentages. RCA was produced from concrete waste whereby specimens that had been tested in the laboratory were crushed to produce RCA. The following concrete mixes were produced: control mix, CRCA replacement at 50%, 75%, and 100%, FRCA at 50%, 75%, and 100%, and both fine and coarse at 50%, 75%, and 100%. The mix ratio was kept constant as 1:2:4 in all mixes for better comparison and uniformly graded aggregate was used for all mixes. The concern of the study was based on determining the mechanical properties (compressive and tensile strength) of Recycled Aggregate Concrete (RAC) against Natural Aggregate Concrete (NAC). For all the mixes, cylindrical specimens were prepared, and compressive and split-tensile tests were performed with the help of a Universal Testing Machine (UTM). The analysis of test results showed that concrete containing coarse aggregate replacement exhibited encouraging outcomes in concrete mechanical properties; thus 50% replacement of natural coarse aggregate appeared less appropriate as its reduction in strengths would be even slightly below the norms. But when both the fine and coarse aggregate were replaced the strength of normal concrete was declined and the above concrete was not suitable for applications where high strength required.

1. Introduction

Concrete is one of the most consumed building materials and, with the current use of about 30 billion tons per year. The destruction of old buildings and structures requires the use of conventional concrete, and much of this waste product is usually channeled to landfills, which causes more pollution of the environment [1]. This has also contributed to the scarcity of the basic raw materials necessary for concreting works which include cement, sand, and aggregates which later make up about 70-80% of concrete [2D]. This condition regarded the issue of natural aggregate supplies and upline the importance of considering other materials for use.

The construction industry has effectively begun participating in strategies that can lead to environmental and resource conservation. Reclaimed material seems to be among the most effective coming with its preferred application in the production of concrete. The preparation of concrete materials influences the environment and in the earlier past, concrete used large proportions of fine and coarse aggregates obtained from natural sources such as sand, gravel, and crushed stones [3]. But the continuous use of this concrete is posing a big threat to the natural aggregates thus contributing to the following ecological impacts. The detrimental effects of construction waste on the environment can be effectively managed if there are proper measures put in place such as recycling the waste, particularly the crushed concrete in place of the natural aggregates. Besides the fact that crushed concrete which is obtained from old structures that have been demolished and construction debris cuts the raw material needs, there is efficiency in the management of waste material [4].

Concrete with recycled aggregates differs from concrete that is made from natural resources in that the latter possesses the following characteristics; Generally, concrete made from recycled aggregates has low strength as compared to conventional concrete. This decline in strength can be linked to various aspects related to the properties of re-used aggregates and their integration with the new concrete [5]. This is primarily because in Recycled Aggregate Concrete (RAC), many factors that lead to the degradation of the reduced strength include the deposition of old mortar on the original aggregate particles of the crushed concrete is weaker and more porous as compared to the original aggregate and transfers such weaknesses to the new concrete. It suggested that the old mortar can develop a sort of conformal layer around the aggregate particles; thus, the bond strength between the new cement paste and aggregates is influenced, and it affects compressive as well as tensile strengths [6]. Also, RCA are usually more angular and have a greater fragmentation compared to NA, which in turn, affects the packing efficiency, which decreases the density and the overall strength of the concrete mix [7]. Recycled aggregates also present rigid impurities that include old mortar, gypsum, wood, and other chucks which make the new concrete weaker. In addition, crushed concrete is generally more porous compared to natural stone aggregates which results in higher water absorption potential than that of natural stone aggregates and thus the possibility of attaining a lower water-cement ratio which negatively affects the obtainable concrete strength.

The works, which are emphasized in this study, involve the physical and mechanical properties of normal concrete and recycled aggregate concrete (RAC) concerning compressive and tensile strength. The objective of the study also focuses on the behavior of concrete that contains fine recycled concrete aggregates (FRCA), and coarse recycled concrete aggregates (CRCA) instead of natural aggregates. Also, the research includes the analysis of the environmental effects of using crushed concrete aggregates with emphasis on their impact on the utilization of natural resources and dealing with construction waste. This research shall focus on assessing the benefits as well as the drawbacks of using crushed concrete as fine and coarse aggregates in concrete and rating its influence on concrete density and tensile strength.

2. Research Methodology

2.1 General

The purpose of this study is to make a comparison based on the performance of Normal Aggregate Concrete (NAC) and Recycled Aggregate Concrete (RAC) and concerning compressive strength, tensile strength. The research work uses a 1:2:4 ratio in the concrete mix, which is widely used to construct buildings because of its good mechanical properties and is relatively easily workable. This actual mix proportion was adopted to prepare both NAC and RAC so that a direct comparison can be made to observe the effects of [replacement of natural aggregates with FRCA & CRCA].

2.2 Controlled Conditions

To minimize study variables, the method of comparison was kept standard under the following controlled conditions: All concrete

2.2.1 Same Cement Content:

The cement content of all the mixes was kept constant. The ratios of the concrete components did not change but the usage of the recycled aggregates substituted the natural aggregates.

2.2.2 Same Workability:

The factor of workability of the concrete was maintained constant for all types of the mix by optimizing the water-cement ratio by using admixture, and for maintaining equal workability and compacting capacity of the fresh concrete in the environment, constant workability was maintained by using water-cement ratio or admixture.

2.2.3 Same Maximum Grain Size (19mm): The refusal or the largest size of all the coarse aggregates used in all the concrete mixes was 19mm. This way, the observations of any change in a property of the solid due to variation in the size of the aggregates are easily controlled.

2.2.4 Same Quantity of Fine and Coarse Aggregate: The total proportion of fine and coarse aggregates was kept constant in all the mixes because the overall volume and weight should be compared to evaluate the mechanical characteristics of the concrete.

2.3 Types of Specimens

For the current study, ten kinds of concrete specimens were prepared using the mix proportions of 1:2:4. The mix compositions are as follows: The mix compositions are as follows:

1. Normal Concrete (NC)
2. 50% Fine Aggregate Replaced (F50)
3. 75% Fine Aggregate Replaced (F75)
4. 100% Fine Aggregate Replaced (F100)
5. 50% Coarse Aggregate Replaced (C50)
6. 75% Coarse Aggregate Replaced (C75)
7. 100% Coarse Aggregate Replaced (C100)
8. 50% Fine and 50% Coarse Aggregate Replaced (F50C50)
9. 75% Fine and 75% Coarse Aggregate Replaced (F75C75)
10. 100% Fine and 100% Coarse Aggregate Replaced (F100C100)

2.4 Materials

The materials used in this study include:

2.4.1 Ordinary Portland Cement (OPC):

- Kohat Cement, specific gravity 3.15
- Complies with Pakistan Standard PS 232-2008 Grade 53
- Initial Setting Time (IST): Minimum 30 minutes
- Final Setting Time (FST): Maximum 600 minutes

Figure 1: Kohat Cement

2.4.2 Fine Natural Aggregate:

• Sand, procured from Deans Heights near Board Bazar, Peshawar

• Fineness Modulus: 2.82

• Bulk Density: 1671.22 kg/m³

• Water Absorption: 1.65%

2.4.3 Coarse Natural Aggregate:

• Sourced from Deans Heights near Board Bazar, Peshawar

• Maximum size: 19mm

• Water Absorption: 0.7%

• Bulk Density: 1498.2 kg/m³

2.4.4 Recycled Concrete Aggregates (RCA):

• Derived from crushed concrete waste, including both fine and coarse aggregates

• CRCA density: 1370 kg/m³

• CRCA water absorption: 3.42%

• FRCA water absorption: 5.86%

Figure 2: Concrete waste of laboratory; Figure 3: Jaw Crusher at PCSIR; Figure 4: Concrete waste after crushing

Figure 5: Screening of RCA through sieves)

2.5 Mix Proportions

The ratio for the blend of all concrete mixes is shown in Table 1 below. This mix proportion was maintained in each experimental series to maintain consistency thus the 1:2:4 proportion was used. Such was the advantage of controlling for the fixed ratio; it meant that one could compare results obtained at various levels of natural aggregate replacement with RCA easily. For normal concrete, the water-cement ratio was fixed at 0. 55, while correcting another type of concrete to obtain the required workability of the concrete.

Table 1: Mix Proportions of All Mixes

S.No	Mix ID	Cement (kg)	Natural Sand (kg)	Natural Coarse Aggregate (kg)	Recycled Fine Aggregate (kg)	Recycled Coarse Aggregate (kg)
1	NC	4.66	10.82	19.43	0	0
2	C50	4.66	10.82	9.71	0	9.71
3	C75	4.66	10.82	4.86	0	14.57
4	C100	4.66	10.82	0	0	19.43
5	F50	4.66	5.41	19.43	5.5	0
6	F75	4.66	2.7	19.43	8.26	0
7	F100	4.66	0	19.43	11	0
8	F50C50	4.66	5.41	9.71	5.5	9.71
9	F75C75	4.66	2.7	4.86	8.26	14.57
10	F100C100	4.66	0	0	11	19.43

2.6 Casting of Concrete Samples

2.6.1 Molds Preparation:

Concrete cylinder of 100mm diameter and 200mm height was used as the moulds for casting the concrete samples. The molds were well washed and oiled so that the concrete would not stick to it and so that it could be easily demolded.

Figure 7: Mechanical mixer

2.6.3 Placement of Concrete:

It involved filling the molds with the concrete in two steps each done well with a tamping rod to get rid of any unwanted air and the concrete packed tightly in the molds. The top surface was scraper flat to the required volume and the moulds were left undisturbed to start the setting process of concrete.

Figure 8: Molds filled with mix

2.6.4 Demolding of Specimens:

The specimens were then, after 24h of initial curing, taken out of the mould and immersed in a water curing tank. The submersion made sure that cement hydration was under control as this was critical in the concrete setting process.

Figure 9: Specimens in the tank for curing

2.7 Testing of Specimens

After the curing period of 7 days and 28 days of the concrete specimens, the compressive and tensile strength tests were performed. These specimens were surface-dried before conducting the tests on them.

2.7.1 Compression Strength Test:

A compression test was carried out with the help of a Universal Testing Machine (UTM). The specimens were orientated vertically, and load was applied to them in a sequential gradual manner until the failure point. The compressive strength was calculated using the following formula: The compressive strength was calculated using the following formula:

$$\text{Compressive strength}=\frac{4P}{\pi D^2}$$

where P is the maximum load, and D is the diameter of the specimen.

Figure 10: Universal Testing Machine; Figure 11: Compression Test

2.7.2 Tensile Strength Test:

Conduct of the split tensile test was done to determine the tensile strength of the concrete. Samples were positioned in the horizontal direction of the testing machine, and an application of the compressive load perpendicular to the diameter of the bar led to its splitting. The tensile strength was computed as tensile force divided by the original cross-sectional area of the tape.

$$\text{Tensile strength}= \frac{2P}{\pi LD}$$

where P is the maximum load, L is the length of the specimen, and D is the diameter.

Figure 12: Split-tensile test

3. Results

3.1 Compressive Strength Test Results

The use of Recycled fine and coarse aggregates and their combined proportion in concrete were evaluated in terms of the compressive strength of the concrete specimens at 7 and 28 days. As mentioned earlier, the results presented in Table 4-1 depict a decrease in the mechanical properties with an increase in the content of recycled aggregates. Precisely, for 50% replacement, the experiment result of compressive strength of coarse, fine, and combined recycled aggregate reduced by 8-12%, 13-16%, and 19-21% respectively. For 75% replacement, the reductions were: 16-17%, 18-21%, and 28-29%. Also at 100% replacement, the reductions were as follows, 20-23%, 24-26%, and 35-38%.

Table 2: Compressive Strength of All Mixes

S.No	Mix ID	Compressive strengths (psi)	
		7th day	28th day
1	NC	2416.0	3583.3
2	C50	2129.3	3295.6
3	C75	2009.3	3007.0
4	C100	1860.0	2843.0
5	F50	2036.0	3089.5
6	F75	1921.3	2933.3
7	F100	1768.0	2715.8
8	F50C50	1900.0	2894.7
9	F75C75	1716.7	2563.2
10	F100C100	1496.0	2331.6

The current graphs, namely graphs 13, 14, and 15 demonstrate the outcome of compressive strength at 50%, 75%, and at the maximum replacement level of 100%. It was observed from the data given that at similar replacement levels, the compressive strength of replaced concrete increased a bit more as compared to the replaced coarse recycled aggregate than the fine recycled aggregate. It was found that having both types of recycled aggregates resulted in the maximum reduction of the compressive strength.

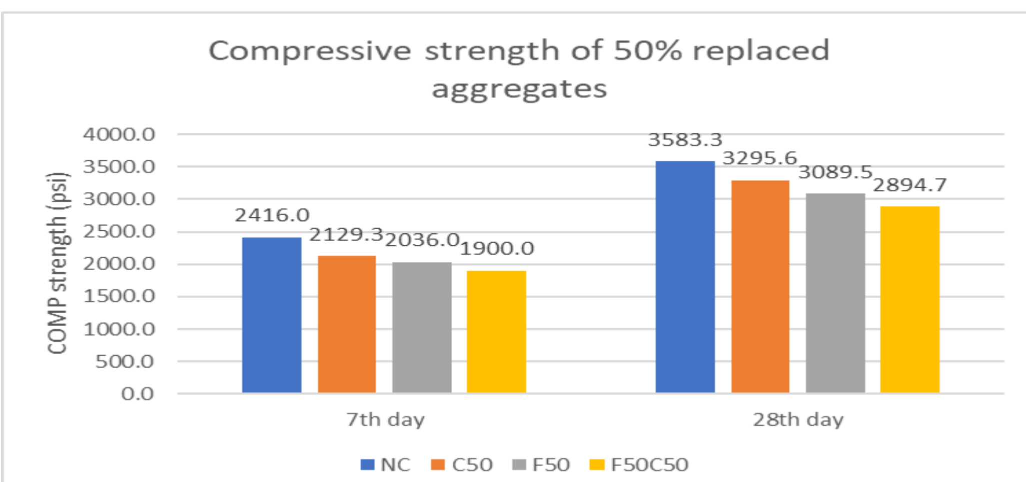

Figure 13: Compressive Strength of 50% Replaced Aggregates

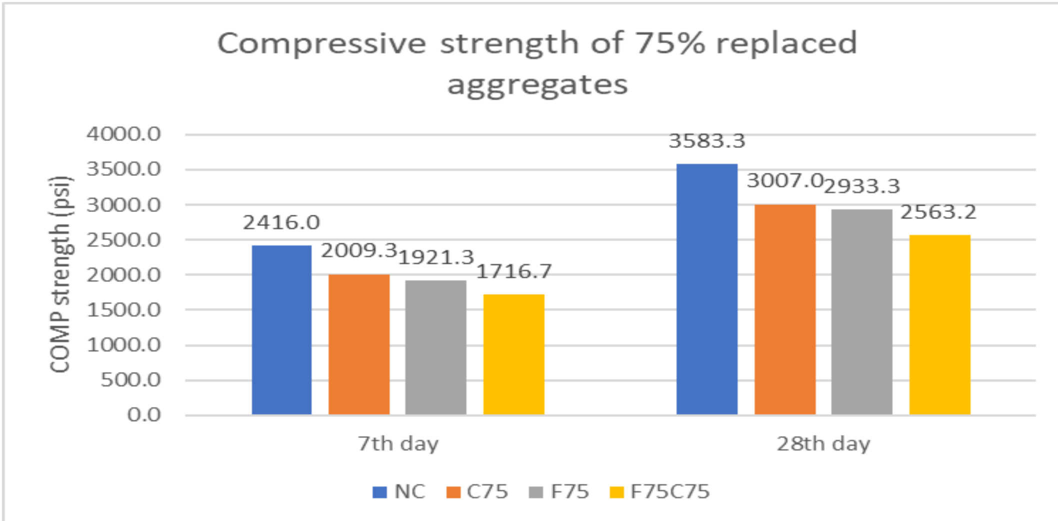

Figure 14: Compressive Strength of 75% Replaced Aggregates

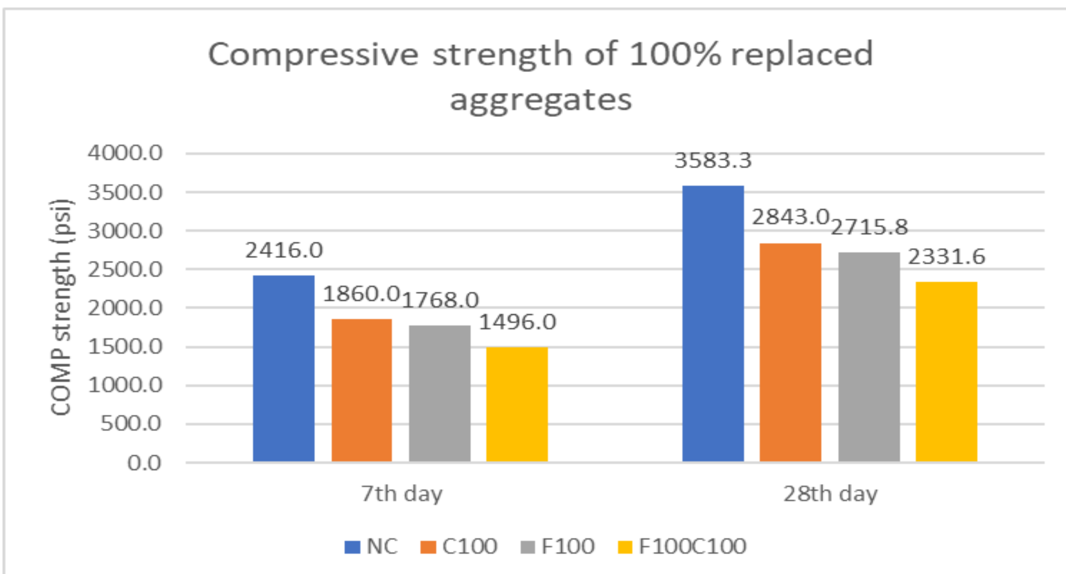

Figure 15: Compressive Strength of 100% Replaced Aggregates

3.2 Tensile Strength Test Results

The tensile strength of the concrete specimens was also determined, and this is shown in the following Table 3. The outcomes of tensile strength prove that there is a decline in this property as the recycle aggregates fraction is raised. For 50% replacement, reduction in the tensile strength of coarse, fine, and combined recycled aggregates was found to be 13-15%, 15%, and 14%. 5-17%, and 19-25%, respectively. In the case of 75% replacement, the shown reductions were 19. 5-21%, 17-19%, and 24-27. 5%. At 100% replacement, the reductions were 20-24 percent. 5%, 18-21. 5%, and 26-31. 5%.

Table 3: Tensile Strength of All Mixes

S.No	Mix ID	Tensile strengths (psi)	
		7th day	28th day
1	NC	261.7	392.1
2	C50	222.7	340.8
3	C75	210.3	309.2
4	C100	208.5	294.7
5	F50	221	325.7
6	F75	216.2	317.1
7	F100	214.2	308.1
8	F50C50	211.2	293.2
9	F75C75	198.4	284.6
10	F100C100	192.9	269.3

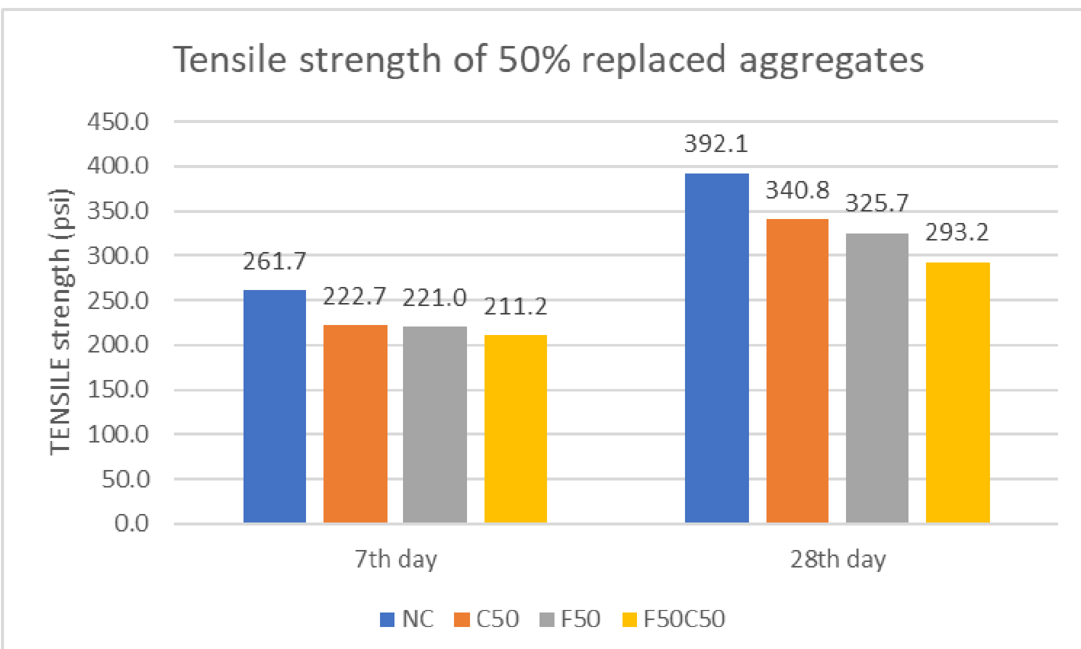

Figure 16: Tensile Strength of 50% Replaced Aggregates

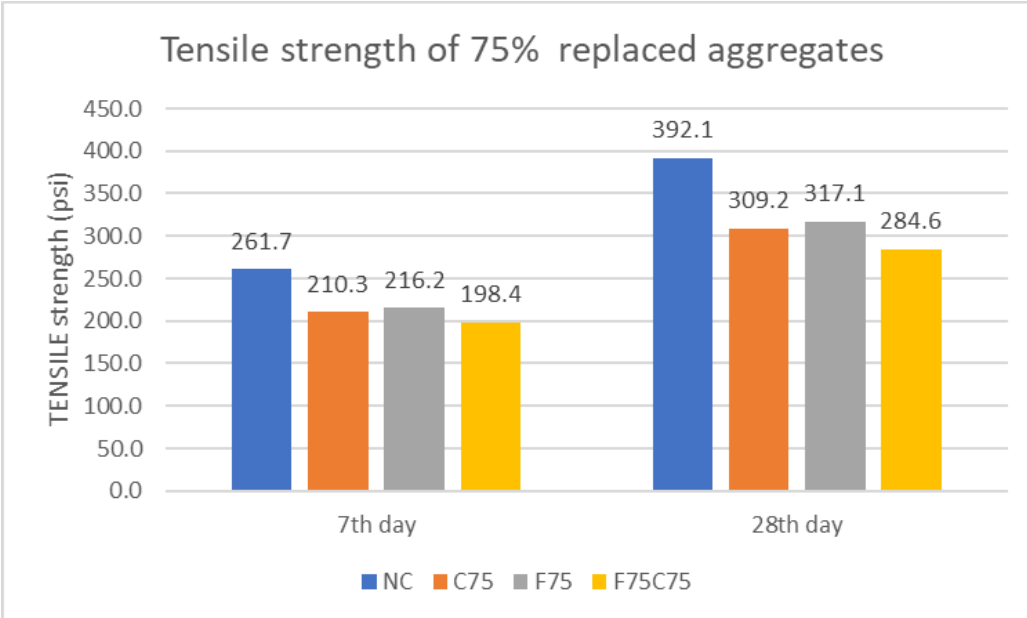

Figure 17: Tensile Strength of 75% Replaced Aggregates

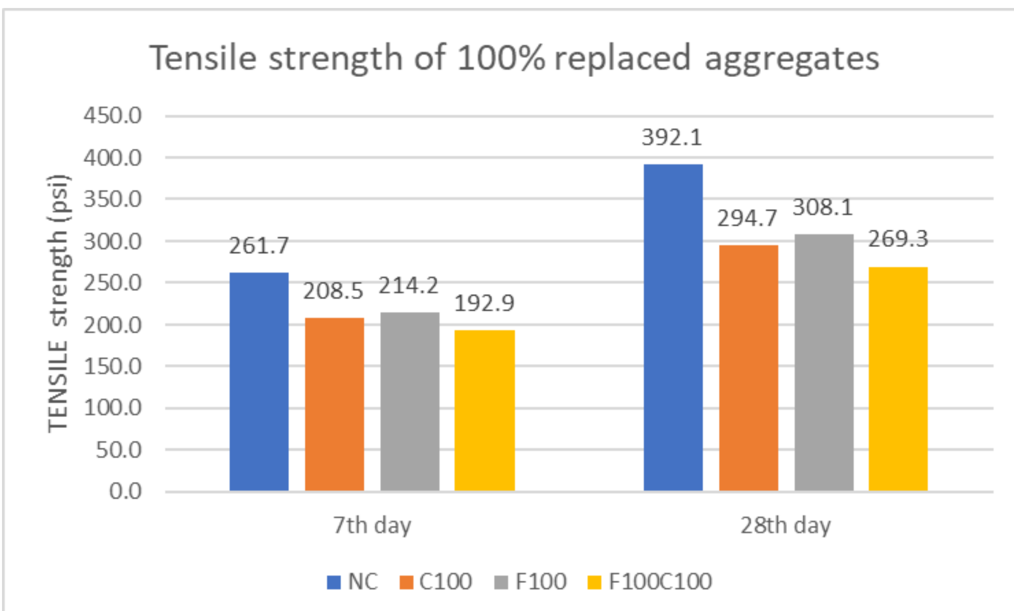

Figure 18: Tensile Strength of 100% Replaced Aggregates

5. Conclusion

Following the conducted study on the use of recycled fine and coarse aggregates in concrete, the following conclusions can be drawn: Following the conducted study on the use of recycled fine and coarse aggregates in concrete, the following conclusions can be drawn:

- But then it is observed that as the percentage of the recycled aggregate increases, there is a reduction in the strength of the recycled aggregate concrete (RAC). The compressive, as well as tensile strength of concrete, decreases gradually as the proportion of recycled aggregate increases.
- From the results of the given work, it can be concluded that concrete with CAR exhibited higher strength than concrete with FAR at analogous levels of substitutions. This infers that concrete made with coarse recycled aggregates is less hazardous as compared to fine recycled aggregates.
- Simultaneous substitution of both fine and coarse aggregates results in a higher decline in the compressive and tensile strengths. More precisely, the total combined replacement option provides the highest reduction in strength 38% compressive and 31% of tensile strength so the option is less effective for structures with high load-bearing capacity.
- From among the investigated replacement proportions of coarse aggregate, the observed low decrease in strength of concrete containing fifty percent average replacement of natural stone with available waste makes it a sustainable solution when integrated with construction since it does not compromise acceptable levels of strength.
- As it is observed to decrease gradually, this can be explained by the fact that old mortar which is still attached to the surfaces of recycled particles reduces the overall strength of concrete. Correct methods of handling and processing recycled aggregates are critical in enhancing the quality of products and reducing the adverse effects of recycled aggregates on concrete.
- Thus, the study points out the need to employ quality recycled aggregates and possibly apply other materials or additives to increase the efficiency of recycled aggregate concrete, which would make construction more sustainable while also meeting structural requirements.

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