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A Theoretical and Experimental Evaluation of the Thermo-Mechanical Properties of Natural and Recycled Aggregate Concrete

Hina Bagri[1], Er. Raj Bala[2]

[1]M Tech Scholar, Department of Civil Engineering, [2]Assistant Professor, Department of Civil Engineering,
[1,2]Jan Nayak Chaudhary Devi Lal Memorial College of Engineering, Sirsa, Haryana, India

ABSTRACT

The utilization of Recycled Concrete Aggregate (RCA) in construction presents a promising avenue towards sustainable waste management and cost-effective material sourcing. This study explores the feasibility of incorporating low strength black steel fibres in recycled aggregate concrete (RCAC), offering potential insights into its compressive behavior, split tensile strength, and durability in acidic environments. Through a comprehensive investigation, this research aims to compare RCAC's mechanical properties with traditional concrete, shedding light on its suitability for structural applications. The experimental framework encompasses a review of literature, detailed testing of raw materials, and rigorous experimentation on RCAC's performance. Results and implications discussed herein contribute to advancing the understanding and application of RCAC in various construction contexts, bridging the gap between research in developed nations and emerging economies like India.

KEYWORDS: *Recycled Concrete Aggregate (RCA), Sustainable construction, Mechanical properties & Black steel fibres*

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INTRODUCTION

Concrete manufacturing and construction industries are increasingly recognizing the economic benefits of utilizing readily available aggregate over the pursuit of ideal materials for every application. Notable advancements in concrete recycling, particularly the production of Recycled Concrete Aggregate (RCA), offer a sustainable solution for specific construction needs. This shift towards RCA usage not only reduces material costs but also aligns with waste management principles, prioritizing recycling over landfilling. In this context, construction and demolition wastes emerge as significant sources of reusable materials, prompting global attention to waste management strategies. As part of this focus, the present study investigates the potential of utilizing recycled aggregate concrete (RCAC) for structural applications, particularly in regions like India where research in this area is still nascent. The objectives of this research include evaluating the mechanical properties of RCAC, particularly its compressive behavior and split tensile strength, as well as assessing its durability in acidic environments. Through a systematic experimental approach, this study aims to contribute to the understanding and application of RCAC, addressing both environmental concerns and the need for sustainable construction practices.

Stages of the Experimental Program

Stage 1	The Research supplies' physical characteristics.
Stage 2	According to IS code, mix design 10262-2019
Stage 3	Cube, and cylinder specimen casting. Conducting tests on cubes and cylinders to determine their compressive and split strength at room temperature.

Cement- As per IS criteria using Grade 43 Ordinary Portland Cement (UltraTech) is used, which conforms with IS: 8112-1989.

Mix Design

Sr no	Highlights	Result
1	Grade designation	40
2	Category of cement	OPC 43 grade
3	Size of aggregate	20 mm
4	Aggregate type	Angular crushed
5	The cement's specific gravity	3
6	The coarse aggregate's specific gravity	2.9
7	The fine aggregate's specific gravity	2.64
8	Minimum amount of cement	320 kg/m³
9	Maximum amount of cement	450 kg/m³
10	Exposure condition	Moderate
11	Workability	100 mm
12	Use of standard code (Indian)	IS 456-2000, IS 10262-2019
13	Water cement ratio	0.425
14	Fineness of sand	4%

TEST PERFORMED ON ALL MATERIAL WITH READING-

Specific gravity of coarse aggregate = 2.9, specific gravity of fine aggregate = 2.64, and specific gravity of cement = 3.

specific gravity of the water = 1

Fineness of cement = 2%

Fineness of sand = 3.96%

Impact value of aggregate = 27.78

Los angles experiment value of aggregate = 18%

Devil Attrition value = 9.7%

Bulking of sand = 4 %

Flakiness of aggregate = 28%

Water absorption of fine aggregate = 0.50

Water absorption of fine aggregate = 0.48

TARGET MEAN STRENGTH-

fck = target average strength for 28 days

fck = characteristics compressive strength at 28 days

s = standard deviation

s = 5N/mm2 (as per table no. 1)

therefore, target strength = 40+1.65*5=48.25

SELECTION OF WATER-CEMENT RATIO-

Maximum water-to-cement ratio from IS 456-2000 table no. 5 = 0.45

calculated water cement ratio = 0.425

VOLUMES:-

Volume of cube concrete = 15 x 15 x 15 =3375cm3

Volume of cylinder concrete = π x 7.52 x 30 = 5301.45 cm3

Total volume = 8676.45

Add 10% extra volume = 9544.095 cm3

Volume of concrete = (1 / 3) + (1.57/2.64) + (2.87/ 2.9) +(0.425 / 1) = 2.339m3

DETERMINATION OF CEMENT CONTENT-

Weight of cement = (1 / V) x volume = (1 / 2.339) x 9544.095) = 4.08kg

DETERMINATION OF FINE AGGREGATE-

Weight of fine aggregate = 1.57 x 4080.41 = 6.40kg

DETERMINATION OF COARSE AGGREGATE-
Weight of coarse aggregate = 2.87 x 4080.41 = 11.71kg

DETERMINATION OF WATER CONTENT-
For 20 mm coarse aggregate use water content 186 litre
Required amount of water = 0.425 x 4080.41 = 1.73 litre

TOTAL MATERIAL REQUIRED ONE SPECIMEN OF COMPRESSIVE AND SPLIT TENSILE STRENGTH-
Weight of total cement = 4.08 kg
Weight of total fine aggregate = 6.40 kg
Weight of total coarse aggregate = 11.71 kg
Required water content = 1.73 litre.

Natural aggregates-Locally available Karnal Sand that meets IS 383-1970's Table 4's as fine aggregate, grading zone II has been used.

Coarse aggregate (Natural)- Crushed coarse Aggregate material that was accessible locally was employed. One has to know the density, specific gravity, and water aggregate content of concrete in order to determine the mix proportions.

Recycled coarse aggregates- The waste concrete from the ruination of ancient buildings in Sirsa (Town), Haryana, India, is used to make recycled aggregate.

Water- The concrete has been mixed with potable water. several testing for drinkable water in permissible limits.

Super Plasticizer- Complots SP-430 A2 were used at the needed dosage to produce concrete with high workability.

Fiber- For economical reasons, the fibre used in the present experiment is locally available black steel wire, also known as binding wire.

Reinforcement- "Under the code, a minimum of four 10 mm diameter bars were inserted into the beam, two in tension (bottom) and two in compression (top)."

Mix design- According As to the literature, the ACI methodology is more suited for designing concrete with recycled aggregate (Bairagi, 1990). For this reason, the Mix Design has been obtained by IS code 10262-2019.

Workability test:- In compliance with IS 3.5, the slump test 1199-1959 is performed on regular concrete, recycle aggregate mixed concrete to assess workability. Workability decrease as the amount of recycle aggregate increase.

Compressive strength test15

It was conducted according to IS code 516-1959. After 7 and 28 days of wet curing the specimen whole samples were taken and examined. The samples analysed using a cube testing instrument (CTM) equipped with a 1000kN capacity for compressive strength. Compaction strength of the specimen was determined by dividing the compressive load area under compression after load was applied progressively and without shocks until the specimen collapsed.

CONCRETE SPECIMEN ON COMPRESSIVE STRENGTH TESTING MACHINE & TESTING CUBE FAILURE

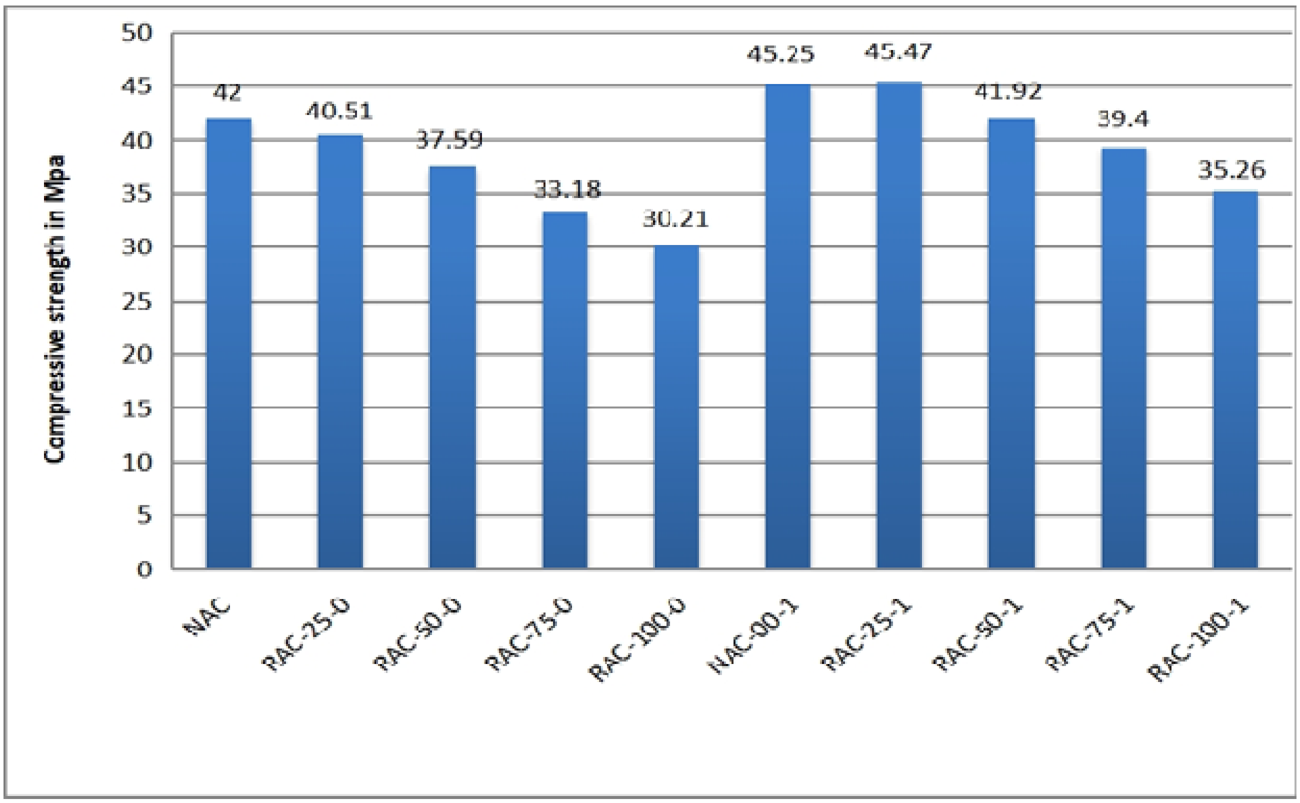
COMPRESSIVE STRENGTH FOR 7 DAYS

Sr. No.	Sample No.	Recycled aggregate and reinforced fiber used (%)	Compressive Load (KN)	Compressive strength of cube (N/mm2)	middling compressive strength of cube (N/mm2)
1	1	NAC	940	41.78	42
	2		945	42	
	3		950	42.22	
2	1	RAC-25-0	905	40.22	40.51
	2		910	40.44	
	3		920	40.88	
3	1	RAC-50-0	850	37.77	37.59
	2		840	37.33	
	3		835	37.67	
5	1	RAC-75-0	760	33.77	33.18
	2		750	33.33	
	3		730	32.44	
6	1	RAC-100-0	680	30.22	30.21
	2		670	29.77	
			690	30.66	
7	1	NAC-00-1	1010	44.88	45.25
	2		1015	45.11	
	3		1030	45.77	
8	1	RAC-25-1	1020	45.33	45.47
	2		1040	46.22	
	3		1010	44.88	
9	1	RAC-50-1	940	41.77	41.92
	2		960	42.66	
	3		930	41.33	
10	1	RAC-75-1	890	39.55	39.40
	2		890	39.55	
	3		880	39.11	
11	1	RAC-100-1	790	35.11	35.26
	2		810	36	
	3		780	34.67	

Split Tensile Test- Cylinders were employed for the test in compliance with IS code 516-1999. Samples from the water were collected. Split tensile testing apparatus with a 2000 KN capacity was used to test the in compliance with IS 516. Split tensile strength is estimated using the split tensile strength equipment shown below: The weight was raised gently and steadily without causing any shocks to the specimen after the first fracture formed. When DL, D, and P are the cylinder's length (300 mm), diameter (150 mm), and failure load (P), the split tensile strength (MPa) is equal to 2P/DL.

Acid Resistant test- Concrete is vulnerable to acid attack due to its alkaline nature. When constituents of cement paste come into contact with acids, they dissolve. The most prominent reaction involves the dissolution of calcium hydroxide the porosity of the cement paste, the concentration of the acid, and the circulation of fluids through the concrete conduits. Insoluble calcium salts may infiltrate crevices and hinder further deterioration. Nitric acid and other acids can exacerbate this process.

Table 4 COMPRESSIVE STRENGTH FOR 7 DAYS

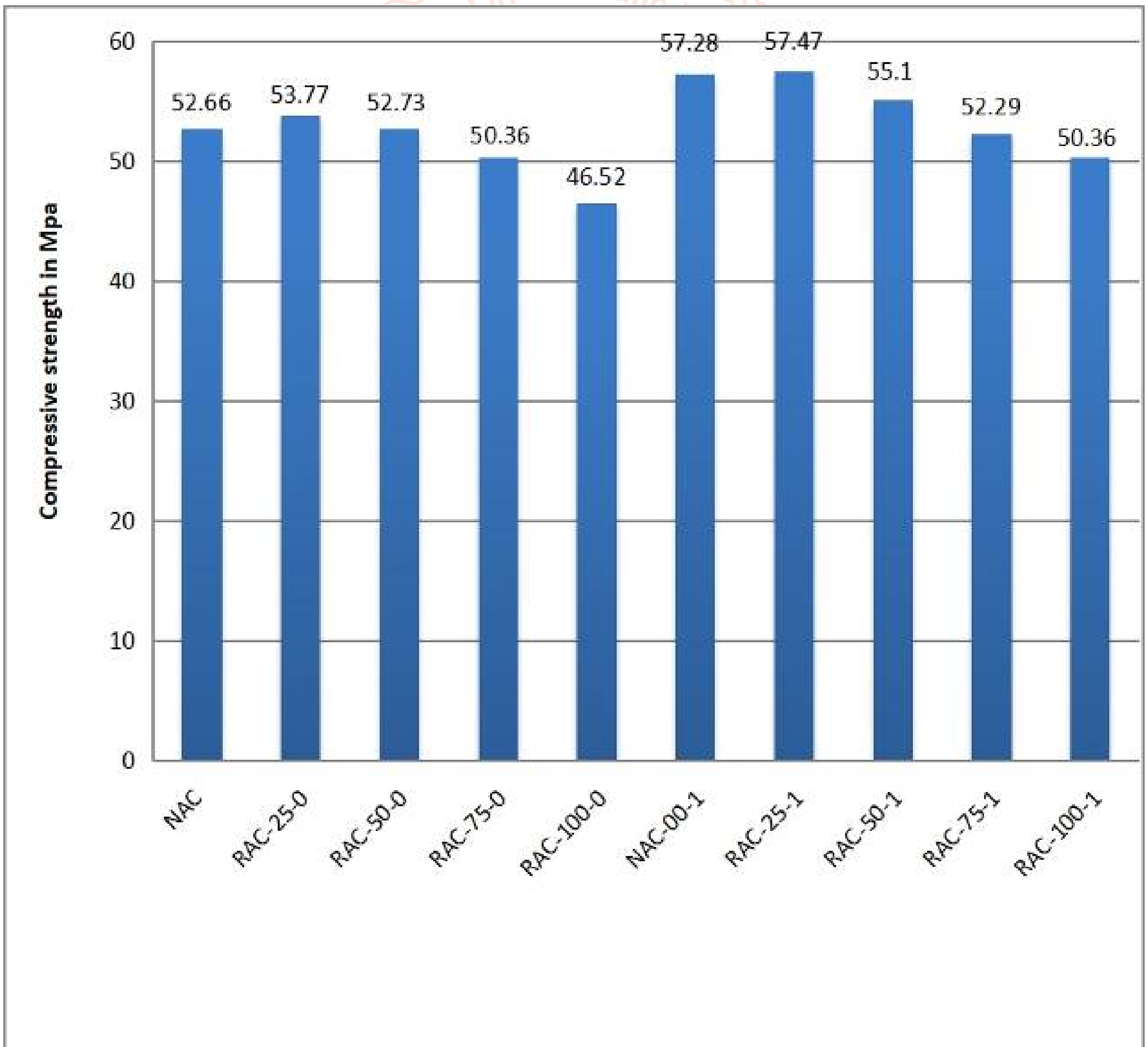


COMPRESSIVE STRENGTH FOR 7 DAYS

COMPRESSION STRENGTH DATA AT THE AGE OF 28 DAYS

Sr. No.	Sample No.	Recycled aggregate and reinforced fiber used (%)	Compressive Load (KN)	Compressive strength of cube (N/mm2)	Average compressive strength of cube (N/mm2)
1	1	NAC	1195	53.11	52.66
	2		1190	52.88	
	3		1170	52.00	
2	1	RAC-25-0	1220	54.22	53.77
	2		1210	53.77	
	3		1200	53.33	
3	1	RAC-50-0	1200	53.33	52.73
	2		1190	52.88	
	3		1170	52.00	

4	1	RAC-75-0	1145	50.88	50.36
	2		1135	50.44	
	3		1120	49.77	
5	1	RAC-100-0	1050	46.67	46.52
	2		1030	45.78	
	3		1060	47.11	
6	1	NAC-00-1	1290	57.33	57.28
	2		1270	57.20	
	3		1290	57.33	
7	1	RAC-25-1	1300	57.77	57.47
	2		1290	57.33	
	3		1290	57.33	
8	1	RAC-50-1	1230	54.66	55.10
	2		1250	55.55	
	3		1240	55.11	
9	1	RAC-75-1	1180	52.44	52.29
	2		1170	52	
	3		1180	52.44	
10	1	RAC-100-1	1145	50.88	50.36
	2		1125	50	
	3		1130	50.22	



COMPRESSIVE STRENGTH VARIATIONS FOR 28 DAYS

COMPRESSIVE STRENGTH VARIATIONS AT DIFFERENT AGES

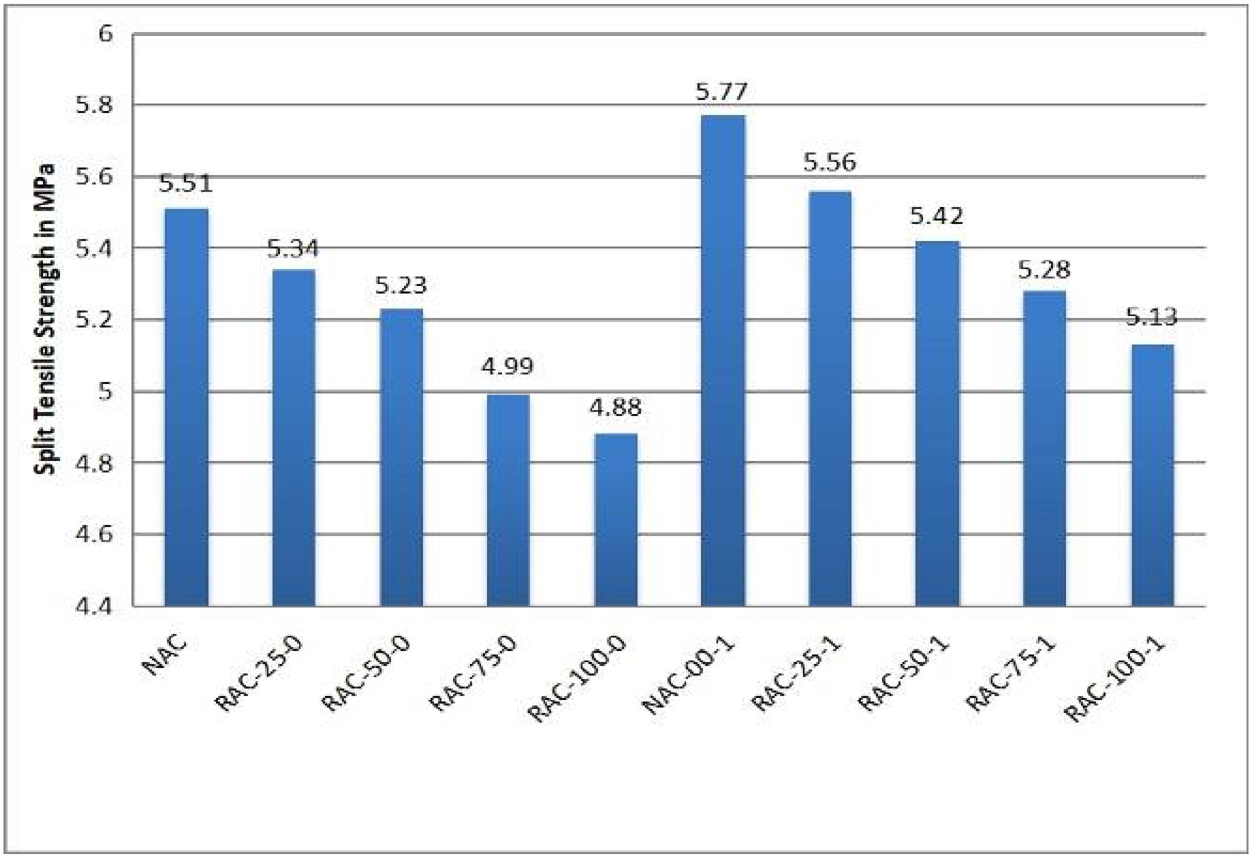
SPLIT TENSILE STRENGTH TEST-

Tables, which provide the split tensile strength of concrete. This strength was evaluated at 7 days with 0% reinforced fiber as follows: for NAC-00-0, RAC-25-0, RAC-50-0, RAC-75-0, RAC-100-0 are 5.51, 5.34, 5.23, 4.99, and 4.88. and for 28 days as follows: NAC-00-0, RAC-25-0, RAC-50-0, RAC-75-0, RAC-100-0 are 6.45, 6.36, 6.24, 6.20, 6.01. The following are the values of compressive strength with 1% reinforced fibre: and for 28 days as follows: NAC-00-1, RAC-25-1, RAC-50-1, RAC-75-1, and RAC-100-1 are 5.77, 5.56, 5.42, 5.28, and 5.13. 6.62, 6.55, 6.4, 6.44, and 4.50 are NAC-00-0, RAC-25-0, RAC-50-0, RAC-75-0, and RAC-100-0. The maximum split tensile strength values with regular aggregate concrete 1% reinforced fibre were found to be 5.77 MPa at 7 days and 6.62 MPa at 28 days. Following this investigation, we discovered that a rise in the quantity of recycled material and reinforced fiber causes a drop in compressive strength. The minimum compressive strength at 7 days and 28 days was 4.88 MPa and 4.50 MPa, respectively, when 100% recycled aggregate is utilized with 0% reinforced fiber and 100% recycle aggregate with 1% reinforced fiber.

SPLIT TENSILE STRENGTH AFTER PERIOD OF 7 DAYS

Sr. No.	Sample No.	Recycled aggregate and reinforced fiber used (%)	Split tensile Load in (KN)	Split tensile strength of specimen (N/mm2)	Average Split tensile strength of specimen (N/mm2)
1	1	NAC	400	5.65	5.51
	2		390	5.52	
	3		380	5.37	
2	1	RAC-25-0	410	5.80	5.34
	2		380	5.37	
	3		350	4.95	
3	1	RAC-50-0	400	5.65	5.23
	2		370	5.23	
	3		340	4.81	
4	1	RAC-75-0	340	4.81	4.99
	2		360	5.09	
	3		360	5.09	
5	1	RAC-100-0	330	4.67	4.88
	2		350	4.95	
	3		355	5.02	
6	1	NAC-00-1	420	5.94	5.77
	2		400	5.65	
	3		405	5.72	

7	1	RAC-25-1	390	5.52	5.56
	2		400	5.65	
	3		390	5.52	
8	1	RAC-50-1	380	5.37	5.42
	2		390	5.52	
	3		380	5.37	
9	1	RAC-75-1	370	5.23	5.28
	2		370	5.23	
	3		380	5.37	
10	1	RAC-100-1	360	5.09	5.13
	2		370	5.23	
	3		360	5.09	

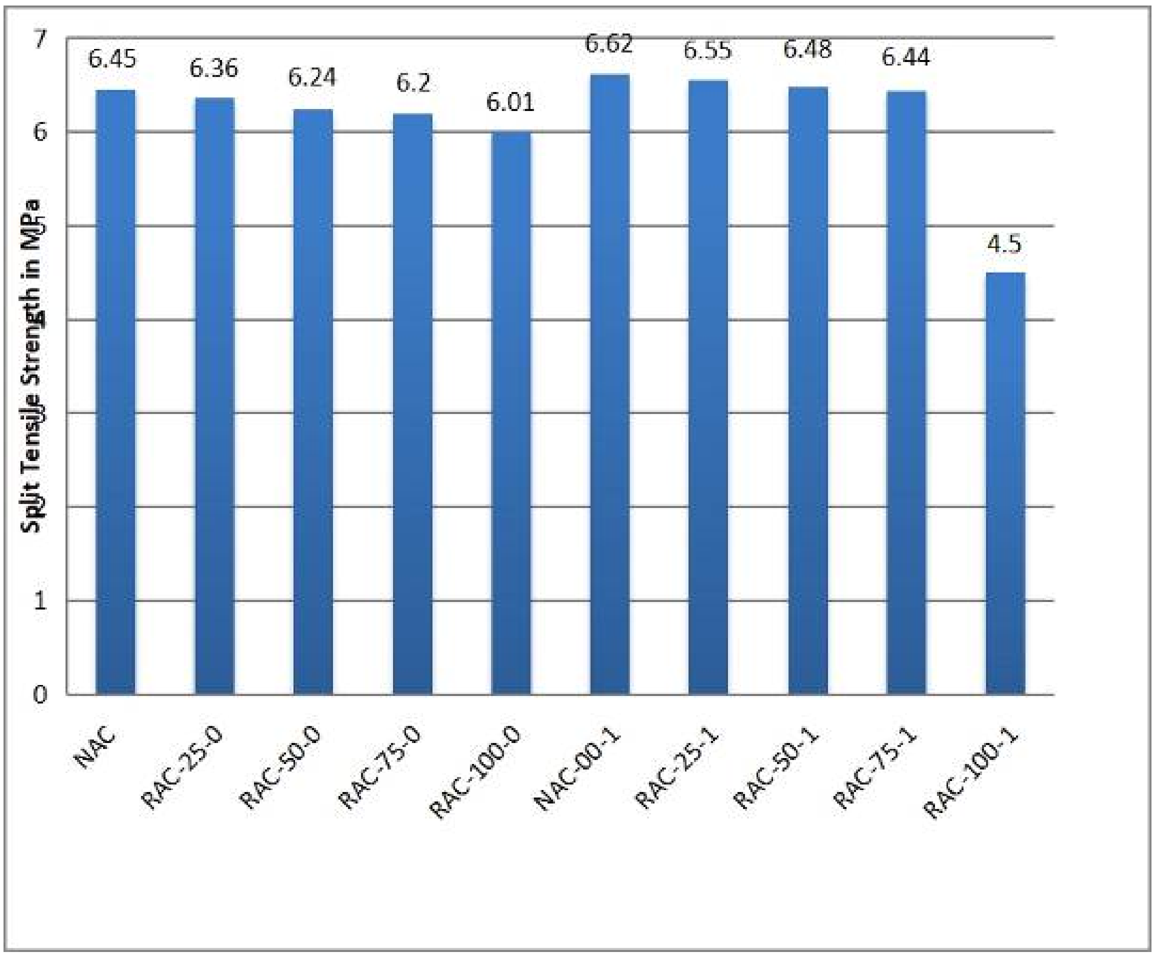


SPLIT TENSILE STRENGTH VARIATIONS AFTER 7 DAYS

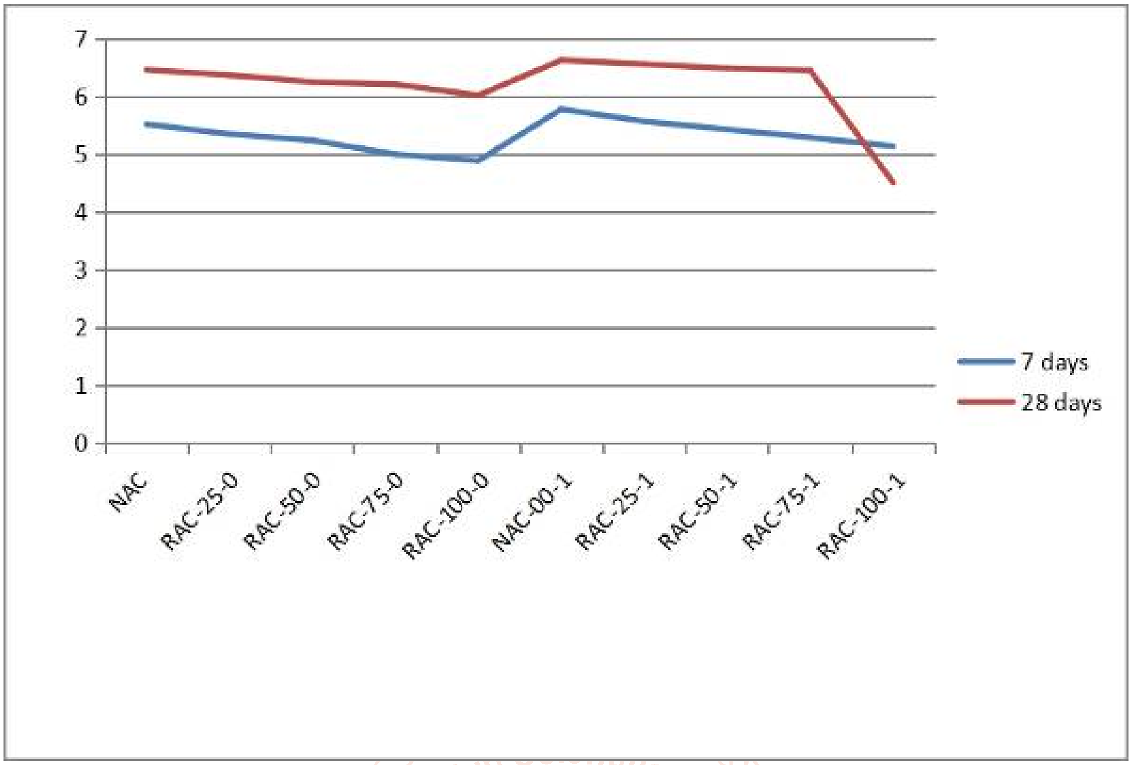
SPLIT TENSILE STRENGTH AFTER PERIOD OF 28 DAYS

Sr. No.	Sample No.	Recycled aggregate and reinforced fiber used (%)	Split tensile Load (KN)	Split tensile strength of specimen (N/mm2)	Average Split tensile strength of specimen (N/mm2)
1	1	NAC	460	6.50	6.45
	2		450	6.36	
	3		460	6.50	
2	1	RAC-25-0	450	6.36	6.36
	2		460	6.50	
	3		440	6.22	
3	1	RAC-50-0	440	6.22	6.24
	2		450	6.36	
	3		435	6.15	
4	1	RAC-75-0	435	6.15	6.20
	2		440	6.22	
	3		440	6.22	

5	1	RAC-100-0	420	5.94	6.01
	2		425	6.01	
	3		430	6.08	
6	1	NAC-00-1	465	6.58	6.62
	2		470	6.64	
	3		470	6.64	
7	1	RAC-25-1	460	6.50	6.55
	2		465	6.58	
	3		465	6.58	
8	1	RAC-50-1	455	6.44	6.48
	2		460	6.50	
	3		460	6.50	
9	1	RAC-75-1	460	6.50	6.44
	2		450	6.36	
	3		460	6.50	
10	1	RAC-100-1	315	4.45	4.50
	2		320	4.53	
	3		320	4.53	



SPLIT TENSILE STRENGTH VARIATION AFTER 28 DAY



SPLIT TENSILE STRENGTH VARIATIONS AT DIFFERENT AGES

Acid Resistant Test- The HCL effects on the compressive strength of concrete are provided in Table 4.7. This strength was assessed after seven days in the following ways: 42, 41.5, 40.2, and 39.1 for HCL-0, HCL-2%, HCL-5%, and HCL-8%; and 56.6, 55.2, 54.6, and 50.0 for HCL-0, HCL-2%, HCL-5%, and HCL-8% after twenty-eight days.

EFFECT OF HCL ON COMPRESSIVE STRENGTH OF CONCRETE AT 7 Days and 28 DAYS

Sr. No.	Grade of Concrete	Cured in Different % of HCL Solution	7days Strength (MPa)	28days Strength (MPa)
1	M40	0%	42	56.6
2	M40	2%	41.5	55.2
3	M40	5%	40.2	54.6
4	M40	8%	39.1	50.0

Conclusion

In conclusion, the study reveals significant insights into the behavior of recycled aggregate concrete (RAC) under compression, shear, and exposure to acidic environments. The compressive strength of RAC exhibits a notable decrease as the percentage of recycled material increases, impacting workability inversely. Additionally, the inclusion of reinforced fibers contributes to increased compressive strength, particularly in mixtures with lower recycled aggregate concentrations. However, the split tensile strength of RAC tends to decrease slightly compared to natural aggregate concrete, with a more pronounced effect observed with higher proportions of recycled material. Moreover, exposure to hydrochloric acid (HCL) results in a significant reduction in the compressive strength of recycled aggregate concrete, emphasizing the vulnerability of RAC to acidic environments.

Future Scope- Utilizing recycled aggregate may reduce building costs and address the issue of disposing of leftover concrete aggregate.

1. Durability testing, including sulphate and acid resistance, may be performed on reinforced concrete strengthened using recycled aggregate.
2. The present investigation is limited to RAC M20 grade concrete, despite the possibility of researching higher grade concrete behaviour.
3. Studies can be conducted utilizing various admixtures, such as silica fume, metabolite, etc.
4. Slabs with various edge conditions and diverse slab forms can be used in experimental studies.
5. used to cast and test real beam models.

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