Mechanical properties of self compacting concrete using different percentage of recycled aggregate

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***Abstract*—This study examines if producing structural concrete with 100% recycled coarse aggregate is feasible without sacrificing the necessary strength performance. Natural aggregates were first used in the design and production of typical concrete mixes of classes M20, M25, M30, M35, and M40. Following a 28-day curing period, these concrete specimens were crushed to produce 10 mm and 20 mm recycled aggregates. The suitability of the recycled aggregates for the manufacture of structural concrete was next assessed using a battery of mechanical and physical tests. Three recycled aggregate concrete mixes—RAC20, RAC25, and RAC30—were created utilising water-to-cement ratios of 0.40, 0.40, and 0.38, respectively, based on trial mix optimisation. To reduce excessive water absorption while mixing, the recycled aggregates were conditioned to a Saturated Surface Dry (SSD) state before batching. After being cast and cured for 28 days, concrete specimens containing 100% RCA were evaluated for compressive strength. According to the experimental findings, the created mixes met the goal strength criteria with average compressive strengths of roughly 28 MPa, 34 MPa, and 38 MPa for RAC20, RAC25, and RAC30, respectively. Additionally, the Two-Stage Mixing Approach (TSMA) improved the concrete's strength and workability, decreased the negative impacts of RCA water absorption, and improved the quality of the interfacial transition zone**

I. INTRODUCTION

The manufacturing and performance assessment of recycled aggregate concrete utilizing 100% recycled coarse aggregates made from crushed concrete waste is the main topic of the current study. The study involves developing appropriate mix proportions, evaluating compressive strength performance at various curing times, and characterizing recycled aggregates by mechanical and physical property testing. The study places special emphasis on using aggregate pre-saturation methods and the Two-Stage Mixing Approach (TSMA) to improve the quality of concrete. The results of this study will encourage the use of sustainable building materials in future infrastructure development and offer useful knowledge about the practical application of recycled aggregates in structural concrete.

To create recycled aggregate concrete (RAC) mixes with 100% recycled coarse aggregates (RCA) and use appropriate mix design techniques to reach the desired compressive strength.

- To determine whether recycled coarse aggregates made from crushed concrete are suitable for use in structural concrete applications by analyzing their mechanical and physical characteristics.
- To examine recycled aggregate concrete's compressive strength performance at various curing ages and contrast the findings with the desired strength specifications.
- To investigate how well the Two-Stage Mixing Approach (TSMA) and aggregate preconditioning reduce water absorption and enhance the workability and strength qualities of RAC.

To encourage sustainable building methods by using trash from construction and demolition as recycled aggregates, which will lessen the impact on the environment and preserve natural aggregate supplies. It is anticipated that the results of this study will aid in the creation of concrete technologies that are affordable, long-lasting, and sustainable for next infrastructure projects.

II. LITERATURE REVIEW

Kumar et al. (2018)

Kumar et al. (2018) examined methods for improving the performance of recycled aggregate concrete through the treatment of recycled coarse aggregates before their incorporation into concrete mixtures. Their research focused on overcoming the inherent limitations of recycled aggregates, particularly the presence of residual mortar, which contributes to high water absorption and reduced mechanical quality. Various surface treatment techniques were applied to modify the recycled aggregates prior to concrete production.

Tošić et al. (2018)
Tošić et al. (2018) evaluated the long-term structural behaviour of reinforced concrete manufactured using recycled coarse aggregates as a complete replacement for natural aggregates. Their study primarily assessed parameters such as creep, drying shrinkage, and the progression of compressive strength over time to determine the suitability of recycled aggregate concrete for structural applications. Experimental observations indicated that recycled aggregate concrete experienced higher creep and shrinkage than conventional concrete because of the porous nature of the recycled aggregates and the residual mortar attached to their surfaces. Despite these increases, the structural performance remained within acceptable engineering limits.

Bai et al. (2020)
Bai et al. (2020) investigated the relationship between recycled aggregate quality and the resulting mechanical properties of concrete. The study demonstrated that the engineering performance of recycled aggregate concrete is strongly influenced by the physical characteristics of the recycled aggregates. Aggregates containing excessive adhered mortar displayed lower density and significantly higher water absorption, leading to reductions in stiffness and compressive strength. Conversely, recycled aggregates that were carefully processed and cleaned exhibited much better mechanical performance. The researchers concluded that proper processing and quality control of recycled aggregates are essential for producing reliable structural concrete with complete or high levels of aggregate replacement.
Li et al. (2020) explored chemical treatment methods aimed at enhancing the quality of recycled coarse aggregates before their use in concrete production. Different treatment procedures were employed to modify the aggregate surface and improve its interaction with cement paste.
The treated aggregates showed lower porosity and a more compact surface compared with untreated materials. This improvement strengthened the bond at the interfacial transition zone between the aggregate and cement matrix, resulting in higher compressive and tensile strengths. The study demonstrated that chemical treatment can effectively reduce many of the disadvantages associated with recycled aggregates and improve the structural performance of recycled aggregate concrete.

Jalilifar et al. (2020)
Jalilifar et al. (2020) examined the influence of supplementary cementitious materials, including silica fume and natural zeolite, on the mechanical behaviour of recycled aggregate concrete. The objective was to improve the internal microstructure of concrete containing recycled coarse aggregates.
The incorporation of these mineral admixtures refined the pore structure and enhanced the bond between recycled aggregates and hydrated cement paste. As a result, improvements were observed in compressive strength, splitting tensile strength, and durability characteristics. The findings confirmed that supplementary cementitious materials can significantly enhance the performance of recycled aggregate concrete while supporting environmentally sustainable construction.

III. CONCRETE MIX DESIGN

The methodical process of choosing suitable component materials and figuring out their ratios to create concrete that meets the necessary requirements for workability, strength, and durability while remaining economical is known as concrete mix design. The main goal is to use resources as efficiently as possible while achieving the desired performance parameters.
The following variables influence the choice and ratios of mix ingredients:

- The required characteristic compressive strength is determined by structural design factors.
- Sufficient workability to guarantee correct placement and compaction with the equipment at hand.

• Appropriate cement content and water-to-cement ratio to attain the required durability under service conditions.

MIX PROPORTIONS

Table 1 Mix Proportions for Natural Aggregate Concrete

Sl. no	Grade Designation	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)	w/c ratio	Target strength (MPa)
1.	**M 20**	300	756	1192	165	**0.55**	27
2.	**M 25**	300	752	1236	150	**0.50**	32
3.	**M 30**	330	725	1242	148.5	**0.45**	38
4.	**M 35**	360	702	1200	162	**0.45**	43
5.	**M 40**	380	681	1220	152	**0.40**	51

CASTING OF SPECIMEN

Table 2. Number of Cubes to be Casted

Type of Mix	% RA	% NA	No of cubes	
M 20	0	100	30	Note: The cubes will be tested for their compressive strengths after 28 days
M 25	0	100	30	
M 30	0	100	30	
M 35	0	100	30	
M 40	0	100	30	

MIX PROPORTIONS, CASTING OF RAC USING TSMA

Type of RAC Mix	Grade of RA	% Replacement of Recycled Aggregates	No of cubes required for		TOTAL
			7 days	28 days	
RAC 20	GA 20	**100 %**	3	3	6
	GA 25		3	3	6
	GA 30		3	3	6
	GA 35		3	3	6
	GA 40		3	3	6
RAC25	GA 20	**100 %**	3	3	6
	GA 25		3	3	6
	GA 30		3	3	6
	GA 35		3	3	6
	GA 40		3	3	6
RAC 30	GA 20	**100 %**	3	3	6
	GA 25		3	3	6
	GA 30		3	3	6
	GA 35		3	3	6
	GA 40		3	3	6
Total number of RAC Cubes = 90					

Specific Gravity of Recycled Aggregates

Table 4.1 Specific Gravity of 20mm recycled aggregates

Description	Grade of the Granite Aggregate				
	GA 20	GA 25	GA 30	GA 35	GA 40
Weight of the sample (g)	1000	1000	1000	1000	1000
Wt. of Vessel + Sample + Water (A) (g)	1988	1987	1982	1986	1982
Wt. of Vessel + water (B) (g)	1350	1350	1350	1350	1350
Wt. of SSD Sample (C) (g)	1003	1005	1003	1008	1007
Wt. of oven dry Sample (D) (g)	995	993	998	995	994
Specific gravity = D / C - (A-B)	**2.73**	**2.70**	**2.69**	**2.67**	**2.65**

Table 3 Specific Gravity of 10 mm recycled aggregates

Description	Grade of the Granite Aggregate				
	GA 20	GA 25	GA 30	GA 35	GA 40
Weight of the sample (g)	1000	1000	1000	1000	1000
Wt. of Vessel + Sample + Water (A) (g)	1980	1977	1971	1971	1972
Wt. of Vessel + water (B) (g)	1350	1350	1350	1350	1350
Wt. of SSD Sample (C) (g)	1003	1002	1001	1002	1005
Wt. of oven dry Sample (D) (g)	995	993	998	995	994
Specific gravity = D / C - (A-B)	**2.67**	**2.65**	**2.63**	**2.61**	**2.60**

Table 4 Specific gravity of natural & recycled Aggregates

Aggregate Type	Specific Gravity	
	10mm	20 mm
Natural Aggregate (NA)	2.69	2.75
Granite Aggregate (GA 20)	2.67	2.73
Granite Aggregate (GA 25)	2.65	2.70
Granite Aggregate (GA 30)	2.63	2.69
Granite Aggregate (GA 35)	2.61	2.67
Granite Aggregate (GA 40)	2.60	2.65

WATER ABSORPTION % OF GRANITE AGGREGATES

Table 5 Water absorption of natural & recycled aggregates

Aggregate Type	Water absorption	
	10mm	20 mm
Natural Aggregate (NA)	0.5 %	0.3 %
Granite Aggregate (GA 20)	5.33 %	2.98 %
Granite Aggregate (GA 25)	5.75 %	3.12 %
Granite Aggregate (GA 30)	5.83 %	3.23 %
Granite Aggregate (GA 35)	5.95 %	3.27 %
Granite Aggregate (GA 40)	6.09 %	3.31 %

DETERMINATION OF AGGREGATE CRUSHING VALUE OF RECYCLED AGGREGATE

Table 6 Aggregate crushing value of 10mm GA's

Description	Grade of the Granite Aggregate				
	GA 20	GA 25	GA 30	GA 35	GA 40
Wt. of Surface Saturated Dry aggregate (g)	2912	3114	2854	2956	2963
Weight- of Fraction passing 2.36 mm IS Sieve (B) (g)	125.0	133.1	112.9	116.7	117.0
Aggregate Crushing Value [(B/A) X 100] %	**42.92**	**42.74**	**39.55**	**39.47**	**39.48**

Table 7 Aggregate crushing value of 20mm GA's

Description	Grade of the Granite Aggregate				
	GA 20	GA 25	GA 30	GA 35	GA 40
Wt. of Surface Saturated Dry aggregate (g)	2756	2965	2856	2846	2801
Weight- of Fraction passing 2.36 mm IS Sieve (B) (g)	82.12	84.97	78.68	75.39	74.08
Aggregate Crushing Value [(B/A) X 100]	**29.79**	**28.66**	**27.55**	**26.49**	**26.45**

Table 8 Aggregate crushing value of natural & recycled aggregates

Aggregate Type	Aggregate crushing value (%)	
	10mm	20 mm
Natural Aggregate (NA)	26.46	22.00
Granite Aggregate (GA 20)	42.92	29.79
Granite Aggregate (GA 25)	42.74	28.66
Granite Aggregate (GA 30)	39.55	27.55
Granite Aggregate (GA 35)	39.47	26.49
Granite Aggregate (GA 40)	39.48	26.45

GRADING OF RECYCLED AGGREGATES

Table 9 Grading of Recycled Aggregates

Sieve Size (mm)	Percentage Passing through Sieves						
	NA	GA 20	GA 25	GA 30	GA 35	GA 40	Standard Limits
40.00	100	100	100	100	100	100	100
20.00	69.15	92.4	97.55	83.75	90.65	94.9	92.5
16.00	28.55	62.45	82.2	44.75	44.65	69	70
10.00	0.47	36.55	45.35	18.65	21.5	2	2.5
4.75	0	0	0	0	0	0	0

Table 10 Fineness Modulus of Recycled Concrete Aggregates

Aggregate Type	Fineness Modulus
Natural Aggregate (NA)	7.020
Recycled aggregate (GA 20)	6.984
Recycled aggregate (GA 25)	6.979
Recycled aggregate (GA 30)	6.975
Recycled aggregate (GA 35)	6.954
Recycled aggregate (GA 40)	6.898

RAC TRAIL MIX COMPRESSIVE STRENGTH WITH DIFFERENT W/C RATIOS

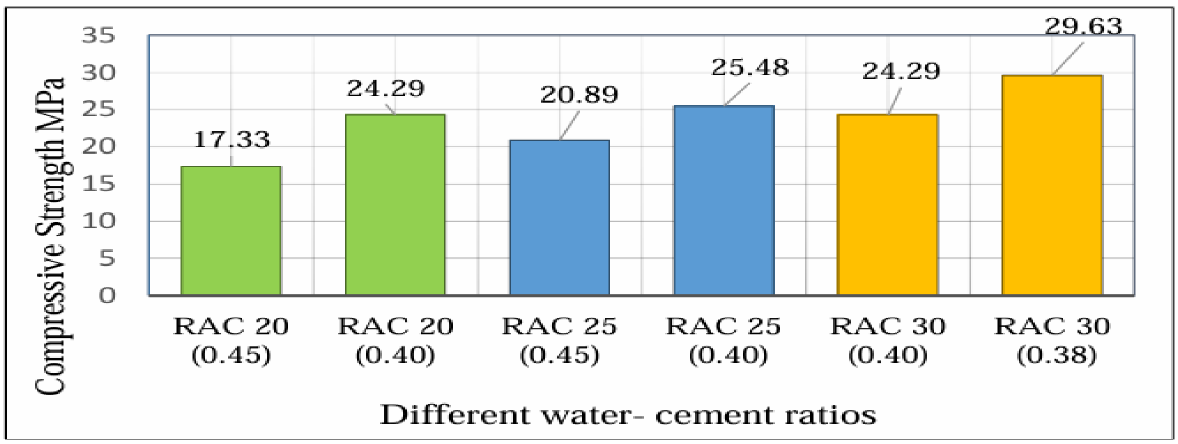

Fig 1.0: w/c ratios vs compressive strength in 100% RAC

DETAILS OF FINAL MIX PROPORTIONS IN RAC

Table11 Details of Weights at 100% Replacement in (RAC 20)

Grade of RAC	Grade of GA	% of RAC	Cement Kg/m ^{3}	Fine Aggregate [Kg/m ^{3}]	Natural Aggregate [Kg/m ^{3}]	Recycled Aggregate [Kg/m ^{3}]	w/c
RAC 20	GA-20	100 %	300	756	0.00	1192	**0.40**
	GA 25	100 %	300	756	0.00	1192	**0.40**
	GA 30	100 %	300	756	0.00	1192	**0.40**
	GA-35	100 %	300	756	0.00	1192	**0.40**
	GA-40	100 %	300	756	0.00	1192	**0.40**
Addition of Super plasticizers conforming to IS 9103							
Conplast SP 430	**Dosage →**		**For GA-20 = 8ml For GA-25 = 8ml For GA-30 = 8ml For GA-35 = 8ml For GA-40 = 8ml**			**8ml of S.P for every 1kg weight of cement**	

Table 12 Details of Weights at 100% Replacement in (RAC 25)

Grade of RAC	Grade of GA	% of RAC	Cement Kg/m 3	Fine Aggregate [Kg/m 3]	Natural Aggregate [Kg/m 3]	Recycled Aggregate [Kg/m 3]	w/c
RAC 25	GA-20	100 %	300	752	0.00	1236	**0.40**
	GA 25	100 %	300	752	0.00	1236	**0.40**
	GA 30	100 %	300	752	0.00	1236	**0.40**
	GA-35	100 %	300	752	0.00	1236	**0.40**
	GA-40	100 %	300	752	0.00	1236	**0.40**
Addition of Super plasticizers conforming to IS 9103							
Conplast SP 430	**Dosage →**	**For GA-20 = 8ml For GA-25 = 8ml For GA-30 = 8ml For GA-35 = 8ml For GA-40 = 8ml**			**8ml of S.P for every 1kg weight of cement**		

Table 13 Details of Weights at 100% Replacement in (RAC 30)

Grade of RAC	Grade of GA	% of RAC	Cement Kg/m 3	Fine Aggregate [Kg/m 3]	Natural Aggregate [Kg/m 3]	Recycled Aggregate [Kg/m 3]	w/c
RAC 30	GA-20	100 %	330	724	0.00	1242	**0.38**
	GA 25	100 %	330	724	0.00	1242	**0.38**
	GA 30	100 %	330	724	0.00	1242	**0.38**
	GA-35	100 %	330	724	0.00	1242	**0.38**
	GA-40	100 %	330	724	0.00	1242	**0.38**
Addition of Super plasticizers conforming to IS 9103							
Conplast SP 430	**Dosage →**	**For GA-20 = 8ml For GA-25 = 8ml For GA-30 = 8ml For GA-35 = 8ml For GA-40 = 8ml**			**8ml of S.P for every 1kg weight of cement**		

COMPRESSIVE STRENGTH (MPA) OF RAC

Table 14 Compressive Strength (MPa) of RAC 20 at 7, 28 Days

Grade Designation	Grade of RA	Target (MPa)	Compressive Strength (MPa)		
			% Replacement	Number of Days	
				7 Days	28 Days
RAC 20	GA 20	28	100% Replacement	24.91	29.33
	GA 25	28		24.59	29.04
	GA 30	28		23.96	28.97
	GA 35	28		23.22	28.63
	GA 40	28		23.18	28.12

Table 15 Compressive strength (MPa) of RAC 25 at 7, 28 days

Grade Designation	Grade of RA	Target (MPa)	Compressive Strength (MPa)		
			% Replacement	Number of Days	
				7 Days	28 Days
RAC 25	GA 20	32	100% Replacement	25.33	33.73
	GA 25	32		24.59	33.34
	GA 30	32		23.96	32.74
	GA 35	32		23.45	32.57
	GA 40	32		23.11	32.13

Grade Designation	Grade of RA	Target (MPa)	Compressive Strength (MPa)		
			% Replacement	Number of Days	
				7 Days	28 Days
RAC 30	GA 20	38	100% Replacement	26.44	41.56
	GA 25	38		25.63	40.96
	GA 30	38		25.11	39.52
	GA 35	38		24.59	38.45
	GA 40	38		23.02	38.12

Grade of RAC	w/c Ratio	Target Strength
RAC 20	0.40	27 MPa
RAC 25	0.40	32 MPa
RAC 30	0.38	38 MPa

VI. CONCLUSION

1. Recycled aggregate concrete (RAC) with 100% recycled concrete aggregates (RCA) was successfully made workable using the Two-Stage Mixing Approach (TSMA). When the recycled aggregates underwent pre-saturation treatment to reach a Saturated Surface Dry (SSD) condition, better performance was noted.
2. • After washing, loose and poorly adherent mortar was removed from the aggregate surface, improving the mechanical and physical properties of recycled coarse aggregates.
3. • It was discovered that lower water-to-cement ratios were required to achieve better compressive strengths in RAC20, RAC25, and RAC30 mixes containing 100% RCA.
4. • Adding a superplasticizer at a dosage of 8 millilitres per kilogram of cement increased early-age strength development and total concrete performance.
5. • After 28 days of curing, the RAC20 mix with 100% recycled coarse aggregates effectively reached the desired compressive strength.
6. • The RAC25 mix achieved the necessary 28-day target compressive strength by completely substituting recycled materials for natural coarse aggregates.
7. • In a similar vein, after 28 days of curing, the RAC30 mix made entirely

VII. FUTURE SCOPE

The following topics are suggested for additional research to improve the knowledge and use of recycled aggregate concrete (RAC) with 100% recycled concrete aggregates (RCA), based on the results of the current study:

• More research is needed to determine whether RAC is suitable for structural applications because of its higher shrinkage characteristics and relatively lower elastic modulus. To evaluate the structural performance of concrete made with 100% RCA, long-term monitoring of deformation behavior, such as elastic modulus, creep, and shrinkage, should be done.

• In-depth microstructural analyses utilizing methods like X-ray diffraction (XRD) and scanning electron microscopy (SEM) are advised to look at the porous interface between the recycled aggregates and adhered old mortar. The Interfacial Transition Zone (ITZ) and the efficiency of micro-filling mechanisms in enhancing bond properties should receive special consideration.

• The mechanisms of crack initiation and propagation in RAC should be the subject of future research. Understanding fracture behavior is crucial for enhancing durability and structural reliability because the residual mortar attached to recycled aggregates may weaken the bond between the old and newly formed cement paste.

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