International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 4 Issue 7 ǁ Jul. 2016 ǁ PP.67-74

A Detailed Study on Recycled Aggregate Concrete using Two Stage Mixing Approach

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ABSTRACT: *The present experimental study deals with pre-soaked slurry two stage mixing approach (PSTSMA) for achieving best mechanical properties. The Recycled aggregate was used in three variant as 30%, 50% and 100% replacements of Natural aggregate in M40 grade of concrete. Through experimental study and analysis, it is observed that using PSTSMA the replacement of 30% RCA with natural coarse aggregate does not more affect the characteristics of concrete. PSTSMA method improve up to 6.35% the strength of recycled aggregate concrete made up of recycled aggregate at 28 days respectively w.r.t. Normal Mixing Approach(NMA). It is observed that concrete prepared with PSTSMA gives better properties than concrete with NMA.*

Key words: *Text Compressive Strength, Split Tensile Strength, Flexural Strength, Interfacial transition zone, Normal mixing approach, Pre-soaked slurry two stage mixing approach, Recycled aggregate concrete, Recycled coarse aggregate.*

I. INTRODUCTION

The term RAC refers to recycled aggregate concrete and it is defined as the concrete prepared by using recycled aggregates or the combination of recycled aggregates and natural aggregates. The recycled aggregates may consist of either fine aggregates or recycled coarse aggregates which are obtained by crushing manually or various manufacturing system of old Concrete structures such as old Buildings, RCC roads, Bridges, tunnel and under water concrete structures sometimes even from catastrophe, such as wars and earthquakes. Developed and developing countries in all over world continues increasing of urbanization, modernization of infrastructure, industrialization which causes the serious problems in construction and demolition waste disposal(C&D) and economically onerous with regard to difficulty to finding new area. In spite with the use of Natural resources and energy increases rapidly. This is also major cause of negative impact on environmental related to the excessive consumption of natural resources. The utilization of recycled aggregate is particularly very promising as 75 percent of concrete is made of aggregates. In that case, the aggregates considered are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand. This can easily be recycled as aggregate and used in concrete. As per the survey conducted by European Demolition Association (EDA) in 1992, the several recycling plants were operational in European countries such as 60 in Belgium, 50 in France, 70 in the Netherlands, 120 in United Kingdom, 220 in Germany, 20 in Denmark and 43 in Italy. In spite with the use of Natural resources and energy increases rapidly. This is also major cause of negative impact on environmental related to the excessive consumption of natural resources. The utilization of recycled aggregate is particularly very promising as 75 percent of concrete is made of aggregates. In that case, the aggregates considered are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand. This can easily be recycled as aggregate and used in concrete. As per the survey conducted by European Demolition Association (EDA) in 1992, the several recycling plants were operational in European countries such as 60 in Belgium, 50 in France, 70 in the Netherlands, 120 in United Kingdom, 220 in Germany, 20 in Denmark and 43 in Italy.

1.1. Following are the main reasons for the use of demolition concrete waste

- The old age of various building, RCC bridges, concrete pavement etc., have limit of use due to structure deterioration and beyond their repairs need to be demolished.
- The some concrete structures not serving in present scenario need to be demolished.
- New construction for better economic growth;
- Structures are turned into debris resulting from natural disasters like earthquake, cyclone and floods etc.
- Building waste produced from manmade disaster/war.

II. MATERIALS AND METHOD

The following materials were used in the present study

Materials Used: Details are presented in table below

Table I Details of Material Used

Name of the material	Source of the materials
Cement	PSC manufactured by Lafarage Concreto
Superplasticizer	Sikament®-581LT/4(K2)
Fine aggregate	Zone II. Obtained from Barakar River, Jharkhand
Coarse aggregate	Obtained crush stone from Pakur , Jharkhand
Recycled coarse aggregates	Recycled Coarse Aggregate obtained from different types of cube mould demolished waste concrete

1.1. Testing of Cement

Portland Slag Cement conforming to IS: 455 were used in the entire experimental study. To avoid the long storage times and to avoid the loss of strength, cement was procured according to the phase wise requirement. The cement was stored in bags in air tight room to have minimum exposure to humidity. The detail of physical properties of cement is presented in table II.

Table II Physical and mechanical properties of cement

Properties	Results	Standard Limits (IS: 455)
Consistency	30%	_
Soundness	Expansion 3mm	<10mm
Initial setting time (min)	70 minutes	>30 min
Final setting time	225 minutes	<600 min
Specific gravity	3.14	_
Fineness	1.83% Retain on 90 micron sieve	<10mm
Compressive strength	N/mm	N/mm
3days	27.33	>16
7days	34.67	>22
28 days	46.87	>33

1.2. Superplasticizer

Sikament®-581LT/4(K2) super plasticizer is used in the present study to maintain the uniform workability in all the concrete mixes. The super plasticizer is brownish colour and available in liquid form and specific gravity is 2.1. A highly effective high range water reducing agent and superplasticizer for free flowing concrete. According to manufacturing data, this Superplasticizer conforming to requirement of IS: 9103- 1999

1.3. Testing of Aggregate

Aggregates are the important constituents in concrete. The fact that the aggregates occupy 70-80% of volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. The test results conducted on fine and coarse aggregate for this thesis are given in table III.

Table III Physical Properties of Natural Fine and Coarse Aggregate and RCA

Properties	Natural Fine Aggregate	Natural Coarse Aggregate	30% RCA + 70% NCA	50% RCA + 50% NCA	100% RCA
Specific Gravity (SSD)	2.613	2.747	2.640	2.586	2.513
Apparent Specific Gravity	2.686	2.791	2.736	2.713	2.70

Bulk Density (Loose) (kg/l)	1.56	1.54	1.49	1.42	1.32
Bulk Density (compacted) (kg/l)	1.62	1.62	1.57	1.51	1.42
Water Absorption (%)	0.931	0.538	1.384	1.829	2.497
Flakiness Index (%)		16.8			8.78
Elongation Index (%)		19.13			13.04
Fineness modulus (%)	2.449	6.687	6.645	6.586	6.486

1.4. Proportioning material for M40 grade of concrete mix

The experimental investigation consisted of making M40 concrete was designed as per IS 10262:2009 and the mix proportions are given in table IV.

Table IV Details of Mix Proportions for RCA (kg/m^3)

Amount of RCA in %	**Cement (kg)**	**Natural FA (kg)**	**Natural CA (kg)**	**RCA (kg)**	**w/c ratio**	**Superplasticizer* in (%)**	**Slump (mm)**
0	407	657	1235	0	0.40	0.8	67
30	407	657	865	336	0.40	0.8	62
50	407	657	617	560	0.40	0.8	54
100	407	657	0	1119	0.40	0.8	51

*percentage by weight of cement

1.5. Method

A manually hand mixing process is adapted. A standard mixing procedure is adopted for all mixes and the procedure is outlined below. Before carrying out the mixing procedure, trial slump tests are conducted with different amount of super plasticizer to the slump in range of 50-75mm for normal concrete and fixed the same amount of superplasticizer for recycled aggregate concrete. Once the slump is obtained in the above specified range, the corresponding quality of super plasticizer is used in the concrete mixing.

Mixing Procedure of the (i) Normal Mixing Approach and (ii) Pre -soaked slurry Two Stage mixing approach shown in fig .1 and 2 and step bellow.

1.6. Different Mixing Approaches

Two method of concrete mixing i.e. "Normal mixing Approach and Two stage mixing approach" introduced by "Tam et al (2005)" has followed through all experimental work with some modification and amendment here so called pre-soaked slurry two stage mixing approach(PSTSMA).

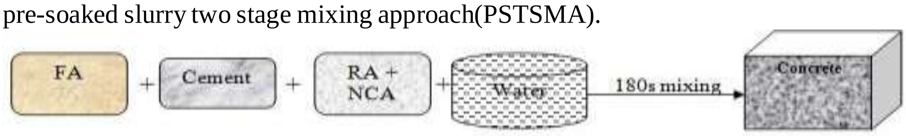


Fig. 1 Normal Mixing Approach

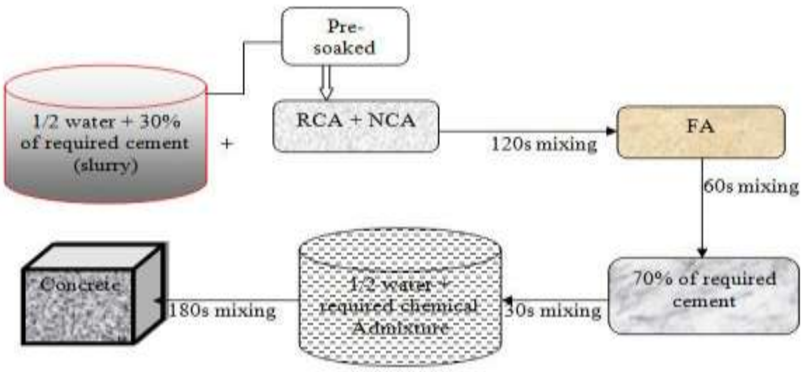


Figure 2 Pre-soaked slurry two stage mixing approach.

III. EXPERIMENTAL RESULTS

3.1 Properties of Fresh Concrete

Table V Test results of workability of both normal concrete and RAC

RCA (%)	Total a/c ratio*	Superplasticizer# in (%)	Slump (mm)		% Improvement
			NMA	PSTSMA	
0	4.65	0.8	67	-	-
30	4.57	0.8	62	64	3.23
50	4.51	0.8	54	57	5.56
100	4.36	0.8	51	54	5.88

The property of fresh concrete is assessed by workability in terms of slump value.
It is observed that in all the mixes the workability decreases with increase in recycled coarse aggregate percentage. This is due to the high absorption capacity and rough surface texture of Recycled Coarse Aggregates but From table V, the workability of concrete slump value increase 3.23% to 5.88% by PSTSMA, In the first stage the slurry formed fills the adhered mortar pore of recycled aggregate and in the 2nd stage amount of water provided full fill for the fluidity of concrete, which reduced the absorption capacity of the mix.

3.2 Mechanical Properties of Concrete

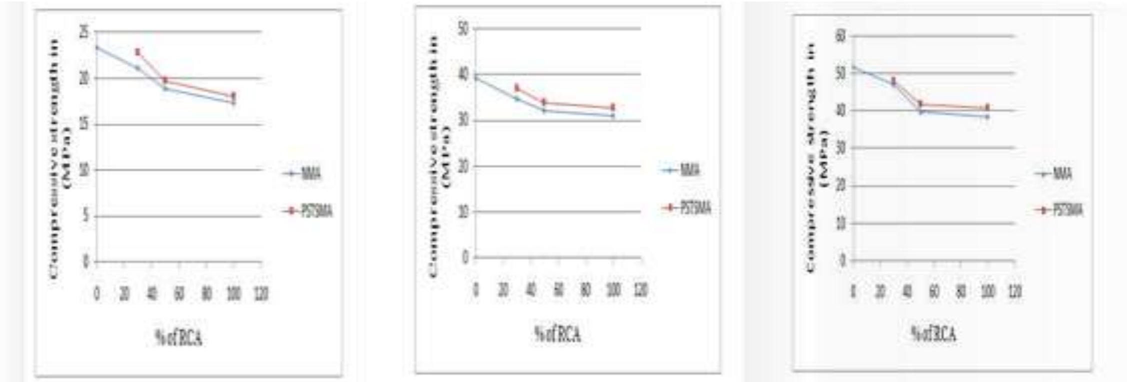
3.2.1 Compressive Strength

The compressive strength of RAC is affected by both the aggregate properties and the characteristics of the new cement paste that is developed during the maturing of concrete. Compressive strength of concrete is directly related to the age after casting and increases with age. 150mm sized cube were made for testing the development of compressive strength under the standard curing condition for 3 days, 7 days and 28 days. This present value is the average of three specimens.

Table VI Comparison of compressive strength result between normal and RAC prepared by NMA and PSTSMA

Mixing method	% of RCA	Compressive strength in MPa			Reduction when compared with 0% replacement		
Days of curing		3	7	28	3	7	28
NMA	0	23.41	39.26	51.63			
	30	21.11	34.74	46.96	9.82	11.51	9.05
	50	18.89	32.15	39.70	19.31	18.11	23.11
	100	17.26	30.89	38.44	26.27	21.32	25.55
PSTSMA	30	22.82	37.03	48.00	2.52	5.68	7.03
	50	19.63	33.85	41.71	16.15	13.78	19.21
	100	18.00	32.67	40.88	23.11	16.79	20.82

Mixing method	% of RCA	Compressive strength in MPa			Improvement when compared with NMA		
Days of curing		3	7	28	3	7	28
NMA	30	21.11	34.74	46.96			
	50	18.89	32.15	39.37			
	100	17.26	30.89	38.44			
PSTSMA	30	22.82	37.03	48.00	8.10	6.59	2.21
	50	19.63	33.85	41.78	3.92	5.29	6.12
	100	18.00	32.67	40.88	4.28	5.76	6.35



Comparison of compressive strength at 3 days age between NMA and PSTSMA   Comparison of compressive strength at 7 days age between NMA and PSTSMA   Comparison of compressive strength at 28 days age between NMA and PSTSMA

Figure 3 Comparison of compressive strength between NMA and PSTSMA

It has been observed that from above fig. 3.

3.2.1.1 The compressive strength of RAC decreases with increase in the amount of RCA using NMA. The main cause for this decrement is high absorption capacity of old mortar adhered to the recycled aggregates and micro cracks in old ITZ.

3.2.1.2 But improvement in the compressive strength is due to PSTSMA in which, during first phase process of mixing cement slurry fill up the micro crack and voids of RA resulting in the improved new ITZ formation**.** However, using PSTSMA method of concrete mixing gives improved compressive strength than NMA, it increases 2.21%, 6.12% and 6.35% at age 28 days replacement of 30%, 50% and 100% respectively.

3.2.2 Split Tensile Strength

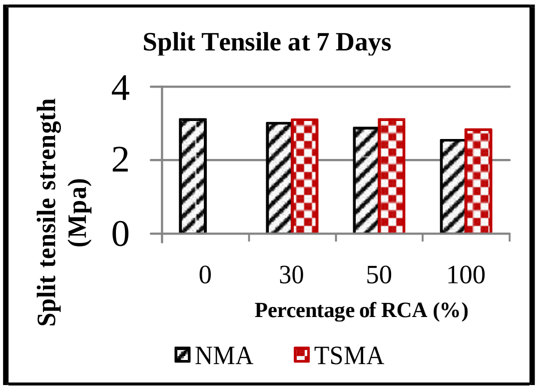
This test was conducted using 1000 KN compression testing machine as per the procedure given in IS: 5816-1999. The split tensile strength test was conducted on cylindrical specimens of 150 mm diameter x 300 mm height at 56 days after curing process.

The values of split tensile strength for different percentages of untreated & treated fibre reinforced concrete after 56 days of Normal water curing & acidic curing are given in table VII & fig. 4.

Table VII Tensile strength of both Natural and Recycled Aggregate concrete

Mixing method	% of RCA	strength in MPa		Reduction when compared with 0% replacement	
Days of curing		7	28	7	28
NMA	0	3.23	3.84		
	30 50 100	2.76 2.59 2.33	3.59 3.30 2.92	14.55 19.81 27.86	6.51 14.06 23.95
PSTSMA	30 50 100	2.90 2.76 2.48	3.80 3.49 3.13	10.22 14.55 23.22	1.04 9.11 18.49

Mixing method	% of RA	Split tensile strength in MPa		Improvement when compared with NMA: %	
Age of curing		7	28	7	28
NMA	30 50 100	2.76 2.59 2.33	3.59 3.30 2.92		
PSTSMA	30 50 100	2.90 2.76 2.48	3.80 3.49 3.13	5.07 6.56 6.44	5.85 5.75 7.19



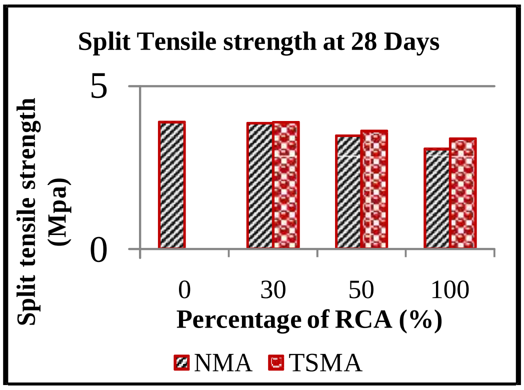


Figure 4 Relative split tensile strength of RAC made with RCA

The value of split tensile strength is decreases in NMA with comparison to PSTSMA due to the refining pore voids, reducing total porosity and improving the interfacial structure between the RA and cement. The split tensile strength of RAC increases by 5.85%, 5.75% and 5.76% replace 30%, 50% and 100% RCA respectively at 28 days curing prepared by PSTSMA than NMA.

3.2.3 Flexural Strength

The flexural strength test was performed in accordance with IS: 516-1959 on the beams of size 500 x 100 x 100 mm after curing period of 28 days with 200 kN universal testing machine. The specimen was supported on two roller support spaced at 400 mm centre to centre.

Table VIII flexural strength of Normal and Recycled Aggregate concrete

Age of curing	% of RA	Flexural strength in MPa		Improvement when compared with NMA: (%)
		NMA	PSTSMA	-
28 days	0	5.85	-	-
	30	5.55	5.80	4.50
	50	5.50	5.77	4.91
	100	4.85	5.00	3.10

- From result, the flexural strength of both normal and recycled aggregate concrete made with different percentage of RCA. It seen that the flexural strength of RAC decrease with increase in recycled coarse aggregate replacement percentage from 30 to 100, percentage reduction shown in table VIII.
- In addition, difference in flexural strength of RAC using method between NMA and PSTSMA. There is 4.50, 4.91 and 3.10% increase in flexural strength of RAC using 30, 50 and 100% of RCA by PSTSMA.

IV. CONCLUSIONS

Based on the experimental work the following conclusion is drawn:-

- The specific gravity and bulk density of recycled coarse aggregate is less than that of natural coarse aggregate as a result in the mix design lesser weight of recycled coarse aggregate is required than natural coarse aggregate.
- The presence of adhered mortar on recycled coarse aggregate produces porous and rough nature of surfaces, which help in developing better bond. But for achieving required workability, the water absorption for recycled coarse aggregate is more than that of natural aggregate.
- Pre-soaked slurry two stage mixing approach (PSTSMA) method is most suitable for production of RAC.
- The recycled aggregate concrete has less workability as compared to the concrete made of natural aggregate; this was due to the porous and rough surfaces of the recycled aggregate. But when recycled aggregate concrete is prepared by PSTSMA, the workability (slump value) increased up to 6.5% due to

pre-mix slurry filling up the pore and cracks of recycled coarse aggregate in 1st stage and remaining water that was added in 2nd stage was not absorbed rapidly by recycled aggregate.

- The compressive strength, split tensile strength and flexural strength of recycled aggregate concrete is less than natural aggregate concrete made by NMA due to pores present in old mortar which developed honeycomb making weaker bond.
- The compressive strength of RAC prepared with PSTSMA showed 6.35% improvement when compared with NMA, due to strengthening of old ITZ by filling slurry gelatin into pores and cracks within the recycled aggregate. This stronger ITZ is responsible for strength improvement.
- Recycled aggregate concrete made with PSTSMA when compared with NMA showed improvement in split tensile strength of about 7%. As mentioned earlier, the ITZ in case of RAC made with PSTSMA is stronger than that in case of RAC made by NMA causing better strength improvement
- Larger quantity of RCA (more than 30%) in RAC reduces the compressive strength and split tensile strength of concrete. However, replacement of natural aggregates with lower (< 30%) RCA has no significant influence on compressive strength and split tensile strength of concrete.
- The reduction in flexural strength of RAC is around 6% by NMA using 50% RCA in RAC when compared with normal aggregate concrete. But the flexural strength of RAC in PSTSMA has strength improvement of about 5% when compared with that of NMA for up to 50% RCA in RAC.
- The disposal of C&D waste causes serious disposal problems, is found to be suitable for using in place of natural aggregates.

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