Shyma Chandrasekharan Int. Journal of Engineering Research and Application www.ijera.com
ISSN : 2248-9622, Vol. 8, Issue3, (Part -V) march2018, pp.27-32

RESEARCH ARTICLE OPEN ACCESS

Development of M40 Grade Recycled Aggregate Concrete by Replacing 100% Virgin Aggregates With Recycled Aggregates and Partial Replacement of Mineral Admixtures

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ABSTRACT
The Increasing Difficulty In Securing Natural Coarse And Fine Aggregates For The Production Of Concrete Coupled With The Environmental Issues And Depletion Of Natural Aggregates Makes The Usage Of Recycled Aggregate. Hence, The Recycled Aggregate Concrete (RAC) Is Very Much Required To Preserve The Natural Resources For Future Generation. And Also Resolve Global Warming Issues To Some Extent. The Study On Recycled Aggregate Concrete Is Very Important As The Aggregate Content Is 60 To 80% Of The Total Volume Of Concrete. However, The Full Use Of The Material Can Be Justified Only Through Structural Engineering Applications. Engineers Are Reluctant To Use RAC In Structural Elements Due To Lack Of Established Design Guidelines. In This Study, An Attempt Has Been Made To Investigate The Mechanical Properties Of Recycled Aggregate Concrete (RAC) Using Mineral Admixtures And Superplasticisers. Basic Characteristics Of Recycled Aggregates Were Determined In The Laboratory. Studies On Pertaining To Recycled Aggregate Concrete (RAC) Of M40 Grade Made Replacing 100 % Virgin Aggregates With Recycled Aggregates Are Presented. The Properties Of Fresh And Hardened Recycled Aggregate Concrete Were Evaluated. The Results Of Compressive Strength Test, Split Tensile Strength, Flexural Strength Tests Are Presented In This Paper.

Keywords **-** Environmental Issues, 100% Recycled Aggregate, Natural Resources, Global Warming Issue, Structural Engineering Applications, Mineral Admixtures, Superplasticisers.

Date of Submission: 19-03-2018 Date of acceptance 02-04-2018

I. INTRODUCTION

The Idea Of Recycling 'Construction And Demolition Waste' Was Conceived After World War II, Due To Bombarding During The Period 1939-45. The Cities Have Become Heaps Of Construction And Demolition Waste. Also Due To Rapid Urbanization The Demolition Of Concrete Buildings Has Been Increased. The Difficulty For Disposing Of Concrete Rubble And Scarcity Of Aggregate Has Prompted An Interest In The Possibility Of Using It As Aggregate In Concrete. Due To Continuous Extraction Of Natural Resources, There Will Be Depletion Of Natural Resources Which Will Have Severe Impact On The Environment.

As Per The World Bank's Survey Made In The Year 2015, Some Important Cities Like Delhi And Mumbai In India, Are Generating A Daily Waste Of About 58,750 Kn And 53,900 Kn Respectively. These Two Cities Are Ranked 9th And 10th Among Top Ten Cities In The World In Generating Daily 'Construction And Demolition Waste'. Generation Of Daily Waste Material Over The Entire World, India Stood At 4th Place. It Is Worth To Mention That About 50% Of The Daily Waste Is The Building Rubble. In This Context, Investigation On Mechanical Properties Of Recycled Aggregate Concrete Has Significant Role. After The World War II, Extensive Research Has Been Carried Out By Substitution Of Recycled Aggregate With Virgin Aggregate But Little Attention Has Been Paid On Usage Of 100 % Recycled Aggregate For Production Of Recycled Aggregate Concrete (RAC) For Structural Concrete.

The Development Of RAC Will Have Remarkable Impact On The Construction Industry By Overcoming Some Of The Problems Associated With Recycled Aggregate Concrete. The RAC Addresses Many Problems Associate With The Higher Water Absorption, Inconsistency In Source, Shape And Size Of The Recycled Aggregate Which Severely Impact On Strength Of The Concrete For Structural Applications. Even After Extensive Research, The Concrete Produced With Recycled Aggregates Is Not Proved So Far That RAC Can Be Used For Structural Applications.

Since World War II, Extensive Research Is Going About Use Of Recycled Aggregate, But Little Focus For Production RAC By 100% Replacing With Recycled Aggregate. After Extensive Research On Grade Less Than M15, 25% Plain Concrete Of Concrete Grade Less Than M25 And 20% For Reinforce Concrete Of Concrete Grade Less Than M25. The Composition Of RAC Is Similar To That Of Normal Concrete, That Is, Cement, Fine And Coarse Aggregates, Water, Mineral And Chemical Admixtures. The Notable Difference Of RAC From Normal Concrete Is That, The RAC Requires More Water, Change In Fraction Of Aggregates, High Range Water Reducing Agents (Super Plasticizers') And Viscosity Modifying Agents (VMA) Which Alter Properties Of Concrete.

Advantages Of RAC Over Normal Concrete Include Control Of Emission Of Green House Gases (GHG) And Many Environmental Issues. Therefore, Use RAC Is Quite Revolution In The Construction Industry. However, The Increase In Water Content And Usage Of Admixtures Make More Sensitive With Reduced Robustness When Compared With Normal Concrete Requiring More Understanding And Greater Quality Control.

As Years Passed, So Far Usage Of RAC Have Not Been Incorporated In Standards In Most Of The Countries Of The World, Though A Lot Of Research Is Going On In Various Aspects Of The Mechanical Behavior And Structural Applications. The RAC Has To Prove, That, Recycled Material Is Efficient And Sustainable Material, There Is A Need To Conduct More Research On The Standardization Of RAC Characteristics And Its Behavior When Used For Structural Elements, Paving Way For The Acceptance Of Its Usage In All Hazardous And In Accessible Project Zones For Grater Quality Control.

Historically, The Development Of RAC, Could Be Seen That Work In This Field Was Initially Limited To Lean Concrete. However, It Has Been Realized With Experience That Strength Is The Only Important Parameter For Production Of Recycled Aggregate Strength Concrete, Other Attributes Such As Durability, Workability, Etc Are Also Important Which Required Exhausting Research For Successful Engineering Of Concrete Structures. This Has Led To The Evolution Of The Concept Of RAC. RAC Can Be Designed To Meet Special Performance Requirements With Regard To Workability, Strength And Durability. To Produce RAC, It Is Normal/General/Necessary To Use Super Plasticizing Chemical Admixtures In Addition To The Same Ingredients, Which Are Generally Used For Normal Concrete. However, Such RAC Requires High Paste Volume, Which Often Leads To Excessive Shrinkage And Large Evolution Of Heat Of Hydration Besides, Increase In Cost.

Use Of Recycled Aggregates, Some Countries Brought Out A Standard Mixes. [1]Bureau Of Indian Standards Incorporated The Use Of Recycled Aggregate, 100% For Lean Concrete Of Concrete

A Partial Substitution Of Cement By Mineral Admixture Such As Ground Granulated Blast Furnace Slag (CGBS) Is Used In This Investigation. Use Of Such Materials Not Only Improves The Properties Of Fresh Concrete But Also Enhances The ITZ (Inter Facial Transition Zone Of The Concrete) Characteristics. When Strength And Durability Is Required, The Use Of GGBS Becomes Imperative, Especially In The Case Of Structural Elements Since GGBS Achieves Early Strength. In Addition, It Improves The Microstructure Of The Concrete. In This Paper, Compared Compressive Strength, Split Tensile Strength And Flexural Strength Of M40 Grade Conventional Concrete With Recycled Aggregate Concrete By Substituting 100 % Virgin Aggregates With Recycled Aggregates.

II. LITERATURE REVIEW

Bhikshma Et Al[1] Investigated On Strength Characteristics Of The Bacterial Concrete With Recycled Coarse Aggregate Concrete With Bacteria, Observed To Be 10% More Compared With RCA Concrete Without Bacteria Culture For M20, 6% More For M25 Grade Concrete And Concluded That, Workability Of Recycled Aggregate Bacteria Concrete Increases By 10% More When Compared To Without Bacteria Concrete. Lokesh Et Al [2] Reported That, The Torsion Decreases With Increase In The Percentage Of Recycled Aggregates And Also Found That Up To 50% Replacement Of Aggregates The Strength Reduction Is Less And Not Even 10% In Case Of Torsion Strength And Concluded The Usage Of Recycled Aggregates Up To 50% Can Be Acceptable. Neville [3] Reviewed The Properties Of Aggregates That Highly Affect The Behavior Of Both Fresh And Hardened Concrete, Namely Strength, Hardness, Toughness, Durability, Porosity, Volume Change, Grain Shapes And Texture, Chemical Reactivity, And Relative Density. Sastry[4] Investigated On Fibrous Recycled Aggregate Triple Blended High Strength Concrete And Concluded That The 28 Days Compressive Strength Of The Triple Blending , The Strength Is Reduced By 20% With Addition Of 100% Recycled Aggregates Used As Replacement To Virgin Aggregates. The Addition Of Steel Fibres Is Helpful In Increasing The Flexural Strength, Splitting Tensile And Young's Modulus With And Without Recycled Aggregate. Kumar [5] Stated That The Deposit Of Coarse-Grained Soil Are A Good Source Of Natural Sand And Gravel. Since Soil Deposits Usually Contain Varying Quantities Of Silt And Clay, Which Adversely Affect The Properties Of

Both Fresh And Hardened Concrete, These Contaminants Must Be Removed By Washing Or Dry Screening. Prasad [6] Investigated On Bamboo Reinforced Concrete And Concluded That The Mechanical Properties Of Bamboo Had Been Found, That The Bamboo Having The Same Properties As Steel Used To Prepare The Test Specimens. Stress Verses Strain Curve Of Bamboo Splint In Tension Shows That Bamboo Is Viscous Elastic Material Having Both Viscous And Elastic Properties And Exhibits Time Dependent Strain Elasticity. The Ultimate Tensile Strength Of Bamboo Splints Is As High As 182 Mpa Which Is Comparable To The Yield Strength Of Structural Steel I.E 250 Mpa. Hence Bamboo Splints Can Resist Sufficient Tensile Loads In A Concrete Flexural Element. Also, Reported That The Even The Modulus Of Elasticity Of 50% Bamboo Replaced Case Gives 15% Variation As Compared To 100% Steel Reinforcement.

RECYCLED AGGREGATES

Fig. 1 Construction And Demolition Waste

Brick Bats And Other Foreign Material Removed From The Demolished Concrete Waste. Recycled Aggregates Are Extracted From Construction And Demolition Waste By Jaw Crusher Available In The Laboratory. Construction Materials Are Increasingly Judged By Their Ecological Characteristics. Concrete Recycling Gains Importance Because It Protects Natural Resources And Eliminates The Need For Disposal By Using The Readily Available Concrete As An Aggregate Source For New Concrete Or Other Applications. Recycling Of Concrete Is A Relatively Simple Process. It Involves Breaking, Removing, And Crushing Existing Concrete Into A Material With A Specified Size And Quality. The Quality Of Concrete With RCA Is Very Dependent On The Quality Of The Recycled Material Used. Reinforcing Steel And Other Embedded Items, If Any, Must Be Removed, And Care Must Be Taken To Prevent Contamination By Other Materials That Can Be Troublesome, Such As Asphalt, Soil And Clay Balls, Chlorides, Glass, Gypsum Board, Sealants, Paper, Plaster, Wood, And Roofing Materials.

RECYCLED AGGREGATE CHARACTERISTICS

Fig. 2 Recycled Aggregates

The Crushing Characteristics Of Hardened Concrete Are Similar To Those Of Natural Rock And Are Not Significantly Affected By The Grade Or Quality Of The Original Concrete. Recycled Concrete Aggregates Produced From All But The Poorest Quality Original Concrete

Can Be Expected To Pass The Same Tests Required Of Conventional Aggregates.Recycled Concrete Aggregates Contain Not Only The Original Aggregates, But Also Hydrated Cement Paste. This Paste Reduces The Specific Gravity And Increases The Porosity Compared To Similar Virgin Aggregates. Higher Porosity Of RCA Leads To A Higher Water Absorption.

Because Recycled Aggregate Contains Mortar From The Original Concrete, It Is More Porous And Absorptive Than Many Natural Aggregates. Test Results Shows That, Recycled Coarse Aggregate Had Water Absorption Of 5% To 6%. Natural Aggregate Typically Has Absorption Of 1% To 2%.

To Test The Effect Of The Aggregates On The Workability Of Concrete, Recycled Aggregate And Natural Aggregate Directly Batched Into Fresh Concrete. The Recycled-Aggregate Concrete Had A Lower Slump Than The Reference Concrete For A Given Water-To-Cement Ratio. The Recycled Aggregate Concrete Required More Superplasticizer Compared To Conventional Concrete To Maintain Adequate Consistency. This Was Attributed To The Angular Shape And, Possibly, Continued Water Absorption Of The Recycled Aggregate.

The Compressive Strength And Splitting Tensile Strength Of The Concrete Were Not Substantially Affected By The Use Of Recycled Aggregate. With 100% Recycled Aggregate, The Flexural Strength, Splitting Tensile Strength Of The Concrete Was About 9.44% And 12.5% Lower Than The Reference Concrete.

When Using 100% Recycled Aggregate, No Significant Differences From The Reference Concrete Were Found On Compressive Strength Of Recycled Aggregate Concrete. Permeability Was Higher Than Reference Concrete, In Which The

Interfacial Transition Zone(ITZ) Recycled Aggregate Concrete Was Improved By Adding 10% GGBS By Weight Of Cement.

III. EXPERIMENTAL PROGRAMMES

The Materials That Are Used For The Present Research Work Are Cement, GGBS, Fine Aggregate, Virgin Aggregates, Recycled Coarse Aggregate, Water And High Water Reducing Agents (Super Plasticizers). Physical Properties Of Coarse And Fine Aggregates Were Studied As Per IS 2386:1963[7] And IS 383:1970[8]. The Properties Of Fine And Coarse Aggregate Are Presented In Tables 5. Potable Water Which Is Free From Chemicals And Organic Materials Was Used For The Study.

Table 1 Physical Properties Of Cement (Opc 53 Grade)

Sl. No.	**Property Of Cement**	**Test Results**	**IS: 12269-1987**[9] **Standards**
1	Specific Gravity	3.15	---
2	Normal Consistency	34%	---
3	Initial Setting Time	53 Min.	Not Less Than 30 Min.
4	Final Setting Time	270 Min.	Not More Than 600 Min.
5	Fineness	3400 Cm^2/Gm	Should Not Be Less Than 2250 Cm^2 / Gm
6	Soundness(Lechatelier)	1.8 Mm	Not More Than 10 Mm
7	Compressive Strength	60 Mpa	53 Mpa

Table 2 Physical Properties Of GGBS

Sl. No.	**Characteristics**	**Properties**
1	Specific Gravity	2.91
2	Specific Surface Area	4070 Cm^2 Per G

Table 3 Properties Of Super Plasticizer

Sl. No.	**Property**	**Results**
1	Form Or State	Liquid
2	Colour	Dark Brown
3	Specific Gravity	1.22
4	Chloride Content	Nil
5	Air Entrainment	Appr. 1%
6	Compatibility	For All Cements
7	Dosage	0.5 To 2.5L Per 100kg

Table 4 Physical Property Of Aggregates

Property		**Natural Aggregate**	**Recycled Aggregate**	**Fine Aggregate**
Bulk Density	Loose	1453 Kg/M^3	1490 Kg/M^3	1740 Kg/M^3
	Compacted	1710 Kg/M^3	1700 Kg/M^3	
Aggregate Impact Value		17.60%	16.80%	-
Crushing Strength		23.80	21.10	-
Fineness Modulus		7.04	7.00	2.78
Specific Gravity		2.74	2.65	2.75
Water Absorption (%)		0.25%	6.00	0.90
Water Content (%)		-	-	3.40
Percentage Voids (%)		-	-	38.75

IV. MIX PROPORTIONING

The Mix Design Was Carried Out As Per IS 10262 (2009) [10] And Absolute Volume Method For M40 Grade Of Concrete. Extra Water (By Weight Of Cement) Was Added To Produce 'Recycled Aggregate Concrete' As The Recycled Aggregates Absorb Relatively Higher Water Compared To Virgin Aggregates. Properties Of Cement, Fine Aggregate, GGBS, Natural Aggregates And Recycled Aggregates Were Investigated. M40 Grade Is Considered In This Paper By Replacing 100% Virgin Aggregate With Recycled Aggregate For Production Of RAC. The Fraction Of 20mm And 10mm Recycled Aggregates Was 60:40 Ratios. The Quantities Of Materials Required For Natural Aggregate Concrete (NAC) And Recycled Aggregate Concrete (RAC) Are Shown In The Table 7.

Table 5 Quantity Of Materials

Material	**Quantity Of Materials(Kg/M^3)**	
Grade	M40NAC	M40RAC
Cement	400.00	405.00
GGBS	---	45.00
Fine Aggregate	660.00	659.60
Coarse Aggregates (20mm)	701.00	617.80
Coarse Aggregates	467.00	505.40

(10mm)		
Water	160.00	165.75
Superplastic iser	2.40	6.75

V. RESULTS AND DISCUSSIONS

7.1 Workability Of Concrete

Workability Of Concrete Was Assessed Using Slump Cone And Compaction Factor Test. It Is Observed That The Slump Of Recycled Aggregate Concrete (RAC) Is Medium. Also It Is Found That Compaction Factor Value Of The RAC Is 0.89 For M40grade. 1.5% Superplasticiser By Weight Of Cement Added To Improve The Workability Of RAC.

Table 6 Test Results Of NAC

Design Mix	Compressive Strength (Mpa)		Flexural Strength (Mpa)	Splitting Tensile Strength (Mpa)
	7days	28days	28 Days	28-Days
M40	36.92	52.65	5.10	3.51

Table 7 Test Results Of RAC

Design Mix	Compressive Strength (Mpa)		Flexural Strength (Mpa)	Splitting Tensile Strength (Mpa)
	7days	28days	28 Days	28-Days
M40	35.29	49.89	4.66	3.12

7.2 Compressive Strength

The Concrete Cubes Of 150 Mm Size Are Cast And Tested To Study The Compressive Strength Under Axial Compression On Completion Of 7 And 28 Days As Per IS: 516-1999[11]. As Per Table 6 & 7, The Test Results Of Compressive Strength At 7 And 28 Days For M40 Grade RAC Is Achieved Target Strength By Replacing 10% Cement With GGBS After Many Trials Mixes Under Controlled Conditions. The Test Results Are Very Satisfactory For M40 Grade Recycled Aggregate Concrete And Encouraging For Production Of M40 Grade RAC With 100 % Replacement Of Natural Aggregates With The Recycled Aggregates. For Production Of M40 Grade RAC Is Possible By Using Procedures Are In Vogue Similar To Conventional Concrete. It Requires No Specific Procedure For Production Of M40 Grade RAC. Replacement Of GGBS Not Only Improves The Strength But Also Improves The Interfacial Transition Zone (ITZ) Results Increase In Density Of Concrete Which Helps To Production Of Durable Concrete Since The GGBS Is Finer Than Cement. Additional Water Required By 'Recycled Aggregates' Is Mitigated By Use Of Superplasticizers.

7.3 Flexural Strength

The Investigation Was Carried Out To Study The Flexural Strength Of M40 Grade Concrete (RAC) At 28 Days. NAC And RAC Prisms Of Size 100 × 100 × 500 Mm Are Cast And Tested At 28days Age As Per IS: 519 -1959[11]. As Per The Test Results Shown In Table 8&9, The Flexural Strength Of M40 NAC Is 9.44% Greater Than RAC Which Attributes To Weak Interfacial Transition Zone (ITZ) Of RAC. Flexural Strength Can Be Achieved By Adding Fibers [17] To Plain Concrete. The Lesser Flexural Strength RAC Could Be The Reason Which Attributes To Inconsistency In The Source, Age, Shape, And Grade And Attached Mortar Of Recycled Aggregates.

7.4 Splitting Tensile Strength

The Investigation Was Carried Out To Study The Split Tensile Strength Of M40 Grade Of Concrete (NAC & RAC) At 28 Days. The Cylinders Of Size 150 Mm Diameter And 300 Mm Height Are Cast And Tested To Study The Splitting Tensile Strength Of Concrete(NAC & RAC) At 28 Days As Per IS: 5816-1970[12]. Splitting Tensile Strength Of NAC Is Greater Than RAC Due To Weak Interfacial Transition Zone (ITZ). Weak ITZ Attributes To Inconsistency In Source, Shape, Age, Grade Of Recycled Aggregates And Attached Mortar. As Per The Test Results Shown In Table 8&9, The Splitting Tensile Strength Of M40 Grade NAC Is 12.5% Greater Than RAC Which Attributes To Weak Interfacial Transition Zone (ITZ) Of RAC. The Difference Of Splitting Strength Is No Concrete Which Can Be Improved By Adding Mineral Admixtures And Fibers To The Recycled Aggregate Concrete.

VI. CONCLUSION

- When Workability Of Recycled Coarse Aggregates Was Tested Using Slump Test And Compaction Factor Test, The Mix Shows Low Workability. This Is Improved By Adding 1.5% Of Superplasticizer (High Water Reducing Agents) By Weight Of Binder.
- Compressive Strength Of M40 Grade RAC Is Achieved Its Target Strength.
- Flexural Strength Of M40 Grade RAC Is 9.44% Less Than Conventional Concrete Which Attributes To Weak Interfacial Transition Zone (ITZ) Of RAC. The Difference Is Not Considerable And Can Be Improved By Adding Mineral Admixtures And Fibers To The Recycled Aggregate Concrete. The Lesser Flexural Strength Of RAC Could Be The Reason Which Attributes To Inconsistency In The Source, Age, Shape, And Grade And Attached Mortar Of Recycled Aggregates.

- Splitting Tensile Strength Of M40 Grade RAC Is 12.5% Less Than Conventional Concrete Which Attributes To Weak Interfacial Transition Zone (ITZ) Of RAC. The Difference Is Not Considerable And Can Be Improved By Adding Mineral Admixtures And Fibers To The Recycled Aggregate Concrete. The Lesser Flexural Strength Of RAC Could Be The Reason Which Attributes To Inconsistency In The Source, Age, Shape, And Grade And Attached Mortar Of Recycled Aggregates.

- The Study Shows That 100% Replacement Of Natural Aggregate With Recycled Coarse Aggregates Gives Satisfactory Results For M40 Grade Recycled Aggregate Concrete. So The 100% Replacement Of Virgin Aggregates With Recycled Aggregates Is Of Much Benefit And Shall Be Encouraged For Structural Applications Duly Extensive Investigation On Durability Properties Of The Recycled Aggregate Concrete.
- Water Absorption In Recycled Aggregates Is 6% More Than Virgin Aggregates Which Affect The Properties Of Concrete. Additional Water Required For Production Of RAC Can Be Mitigated By Addition Of High Water Reducing Agents (Superplasticizers).
- Use Of Recycled Concrete Aggregate (RCA) Is A New Concrete, Test Results Shows That, The Concrete With RCA Performs Equal To Concrete With Natural Aggregates By Replacing 10% GGBS By Weight Of Cement.

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Sidam Gangaram "Development of M40 Grade Recycled Aggregate Concrete by Replacing 100% Virgin Aggregates With Recycled Aggregates and Partial Replacement of Mineral Admixtures"InternationalJournal of Engineering Research and Applications (IJERA) , vol. 8, no. 3, 2018, pp. 27-32