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Mechanical Characteristics of Recycled Aggregate Concrete (RAC) using Alccofine Alongside River Sand and M-Sand

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The increasing scarcity of natural raw materials has propelled the adoption of recycling aggregate from existing concrete in the global construction industry. This study delves into the mechanical properties of concrete comprising 100% recycled material, with a partial substitution of cement by Alccofine 1203. Additionally, the study examines the impact of various mixing techniques on recycled aggregate concrete, employing river sand, M-sand, and superplasticizer. The investigation includes several mixing methods: Surface Coated Aggregate (SCA), Two-Stage Mixing Approach (TSMA), and Double Mixing Methods (DMM). These techniques play a pivotal role in fortifying and augmenting the microstructure of recycled aggregate within the Interfacial Transition Zone (ITZ). By scrutinizing these mixing techniques alongside the use of recycled aggregate and Alccofine 1203, this study aims to provide insights into optimizing concrete production processes, enhancing mechanical properties, and promoting sustainable construction practices.

Keywords: Recycled aggregate concrete, Recycling, Mixing Methods, SEM analysis.

1. Introduction

The surge in Construction and Demolition Waste (CDW) poses a significant challenge for disposal, with escalating volumes attributed to demolition, construction, maintenance, and retrofitting activities. This rapid urbanization, while stimulating economic growth, generates approximately 15 million tons of CDW annually in India. By 2013, Delhi alone was producing 5000 tons of CDW per day, while Chennai reached 1.14 million tons. Such substantial quantities of CDW raise concerns regarding disposal space, pollution, unauthorized dumping, blending with biodegradable waste, and resource depletion. Despite the potential for extensive recycling, India still produces only a fraction of CDW-sourced recycled aggregates. The construction sector's escalating demand for natural aggregates could be alleviated through CDW recycling [1-5]. Therefore, there is an urgent need for a systematic approach to handle, store, and treat CDW in India, emphasizing segregation, reuse, and recycling. Recycling involves converting waste into valuable products, thereby reducing pollution. The process of recycling aggregates involves breaking down structural concrete elements into smaller fragments using various crushers such as hammer mills, jaw crushers, cone crushers, impact crushers, and hammer-based crushing. Mobile crushing plants are increasingly utilized at demolition and construction sites to expedite concrete crushing, reducing transportation costs to recycling plants. Recycled aggregates often retain cement mortar, negatively impacting the strength of new concrete and the Interfacial Transition Zone (ITZ) [6-15]. Treatment methods like nitric acid dissolution, silica fume impregnation, freeze-thaw, thermal expansion, pre-soaking, heating and rubbing, ultrasonic treatment, microwave heating, and mechanical grinding help remove mortar bound to recycled aggregates while preserving their quality [16-27].

The physical and mechanical characteristics of aggregates are affected by the concrete crushing process, impacting the effectiveness of recycling and the parent concrete grade. Techniques such as the double mixing method (DMM), two-stage mixing approach (TSMA), triple mixing method (TMM), and surface-coated aggregate (SCA) mitigate these consequences. The addition of mineral admixtures like fly ash, ground granular blast furnace slag (GGBFS), silica fume, metakaolin, and alccofine enhances various properties of recycled aggregate concrete (RAC), including compressive strength, elastic modulus, drying shrinkage, chloride ion penetration resistance, corrosion resistance, tensile splitting strength, and bonding strength in the ITZ, thereby improving mechanical and durability properties.

Figure 1. Preparation of recycled aggregate for concrete waste using jaw crusher.

a) Old Concrete b) Crushing using Jaw crusher c) Recycled aggregate of 20mm-12mm

1.1 Research Significance

The primary objective of the current research is to examine the mechanical properties of recycled aggregate concrete (RAC) utilizing aggregates sourced from old concrete.

Additionally, the study aims to propose recommendations for the development of novel techniques to improve RAC properties and enhance the Interfacial Transition Zone (ITZ). Key methodologies employed include the Double Mixing Method, Surface Coated Aggregate, and Two-Stage Mixing Approach, all geared towards enhancing the performance of recycled aggregates in concrete applications.

1.2 Experimental Work

In the present research, the natural coarse aggregate underwent complete replacement, with 100% substitution by recycled coarse aggregate. The recycled coarse aggregate was derived by crushing old concrete specimens into smaller sizes utilizing a jaw crusher, as illustrated in Figure 1. Moreover, the study involved the complete replacement of river sand by M-sand and the partial replacement of cement by Alccofine (at a 15% substitution rate), as referenced in [25], to fabricate the recycled aggregate concrete.

2. Materials and Methods

OPC 53grade conformed to BIS specification IS:12269-1987 from UltraTech cement with a specific gravity of 3gm/cc is used in the work. Alccofine-1203 is a micro-fine additive for Concrete & Mortars with a specific gravity of 2.72gm/cc. Based on the scarcity of river sand we replace it with m-sand. River sand and m-sand confining to Zone III guidelines as per IS: 383-1970 with a specific gravity of 2.6g/cc and 2.632gm/cc. Coarse aggregate ranges from 20mm-12.5mm of a natural and recycled coarse aggregate with mortar content produced from various parent old concrete which is initially crushed using a jaw crusher and handpicked manually as shown in the Figure 1 are used; and the details are specified in the Table 1. Sulfonated melamine and naphthalene formaldehyde-based chemical admixture is used.

2.1 DOUBLE MIXING METHOD(DMM):

At first, fine aggregate and recycled coarse aggregates are mixed in this method for 30s and mixed with ½ of the total water content added for 30s and 60s after adding full cement content to get raw concrete (Low water content concrete). Then the remaining water content within the 30s while mixing and continue mixing for another 90s to get the final product.

Table 1.Characteristics of Natural and Recycled Coarse Aggregate.

	Natural Aggregate	Recycled Aggregate
Bulk Density 1. Loose 2. Dry rodded	 1515.67 kg/m^3 1655.05 kg/m^3	 1463.41 kg/m^3 1567.94 kg/m^3
Specific Gravity	2.88 gm/cc	3.0 gm/cc
Impact value	5.25%	7.22%

2.2 TWO-STAGE MIXING APPROACH (TSMA):

Being a two-stage method, the recycled coarse aggregate is added and blended for 10mins in first stage to a mixture of total cement content and water which is initially mixed and in the second stage the fine aggregate and others are added to get the final product.

2.3 SURFACE COATED AGGREGATE (SCA):

The RA was added into an evenly stirred slurry (NitobondSbr + water +cement in the ratio of and 1:1:3) mixed for 5–10 mins and then m-sand is screened in a sieve with mesh sized in the range of 4.75 mm. Cement with Alccofine and Water with SP are added to the concrete.

2.4 TEST PARAMETERS AND TESTING

In current research work, some of the fixed parameters are as follows; impact of replacing cement mortar content with 100% recycled aggregate; impact of the mixing method; impact of adding 15% Alccofine. The researchers performed 100% replacement of the river sand + natural coarse aggregates with m-sand and the recycled aggregate with cement mortar content (here, the content of cement was 349kg/m3 at 0.55 constant w/c ratio). The total cement content is replaced by 15% of alccofine. The dosage of chemical admixture is 0.5% by the mass of cementitious materials. Table 2 details about the proportions of the used concrete mixes. Here, CC represents Conventional Concrete, CA represents cement + alccofine concrete, R and M corresponds to river sand and m-sand, NA and RA denotes natural aggregate and recycledaggregate. The researchers determined the flexural strength, compressive strength and modulus of elasticity in order to assess the impact of mixing method with alccofine at different ages as per standard codes.

Table 2. Mix proportion

Mix Description	W/c ratio	Mix Proportion (kg/m^3)							
		Cement	Alccofine	Water	River Sand	M-Sand	Coarse Aggregate	Recycled Aggregate	Admixture
CCRNA	0.55	349		191.6	665.7		1255.5		
CCMNA	0.55	349		191.6		673.9	1255.5		
CARNA	0.55	296	53	191.6	664		1252		
CAMNA	0.55	296	53	191.6		672.2	1252		
CARRA	0.55	296	53	191.6	649.9			1372	
CAMRA – DMM*	0.46	296	53	163		658		1372	1.745
CAMRA – TSMA**	0.46	296	53	163		658		1372	1.745
CAMRA – SCA***	0.46	296	53	163		658		1372	1.745
DMM* - Double Mixing Method TSMA** - Two-Stage Mixing Approach SCA*** - Surface Coated Aggregate									

Table 3 Compressive strength and percentage of improvement in comparison with alccofine mix over conventional mix and comparison with Alccofine RA mix over Alccofine NA mix.

Mix	Compressive Strength			Improvement when compared with alccofine mix over conventional mix			Improvement when compared with alccofine RA mix over alccofine NA mix		
	7	14	28	7	14	28	7	14	28
CCRNA	22.0	30.3	36.1						
CARNA	27.5	28.3	40.4	25.1	-6	1.9			
CARRA	39.8	44.4	49.3	57.7	37.8	30.8	33.7	47	46.5
CCMNA	23.4	28.6	33.7						
CAMNA	27.7	33.7	39.0	17.1	16.2	14.8			
CAMRA-DMM	28.9	44.9	43.3	21.1	44.3	25.0	4.24	28.5	10

CAMRA-TSMA	34.2	46.8	48.8	37.5	48.2	36.7	21	32.5	22.3
CAMRA-SCA	27.5	30.2	36.2	16.1	5.3	7.2	-0.7	-11	-7.4

3. Results and Discussions

3.1 Slump:

Figure 2 shows the values of slump increases in the recycled aggregate mixes with the addition of chemical admixture. This loss of slump has occurred, primarily due to the attached mortar content over recycled coarse aggregate. The recycled aggregate tend to exhibit a different water absorption range than the variants of parent concrete. So the work is concentrated on the strength and workability since, if excess water is added with the mix, it may degrade the concrete’s durability and strength.

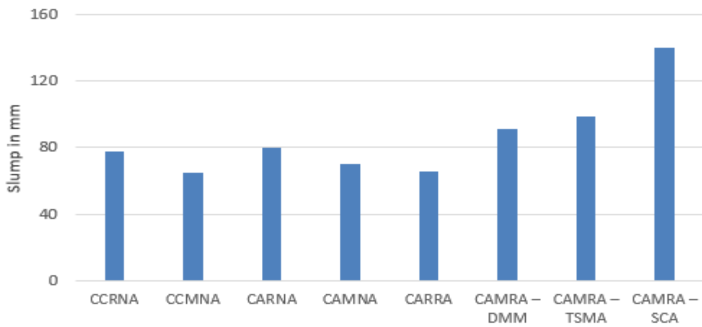


Figure 2. Slump value.

3.2 EFFECT OF ALCCOFINE IN COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE

Table 3 shows RAC’s compressive strength with Alccofine and without Alccofine in both river sand and m-sand with its improvement over the conventional concrete, Alccofine RA mix, and different mixing techniques for RA are shown in Table 3. From the table, it can be inferred that the RAC’s compressive strength with river sand and m-sand is almost the same in CARRA and CAMRA- TSMA mixes showing higher compressive strength than their conventional mixes CCRNA and CCMNA. But in all other mixes, the m-sand mix exhibited excellent strength compared to river sand mix. This might be attributed to angular and rougher texture of m-sand to show higher strength. When compared among CCMNA, CAMNA over CAMRA – DMM, CAMRA –TSMA and CAMRA – SCA, there was an improvement observed in the compressive strength of recycled aggregate, due to mixing techniques, than the natural aggregate.

3.3 MODULUS OF ELASTICITY OF RECYCLED AGGREGATE:

Figure 3 shows the stress-strain relationship between normal aggregate and the recycled aggregate concrete with alccofine. Normally RAC has pronounced effects upon the modulus of elasticity as well as its compressive strength, owing to its porous nature, weak ITZ coupled with cracks. Figure 4 shows the relationship that exists between compressive strength as well as modulus of elasticity of concretes after 28 days. According to the results, there was an increase in the modulus of elasticity of NC and RA concrete with alccofine that aligns with its incremented compressive strength, Further, with acompressive strength in the range of 15.79 N/mm2 and 32.8 N/mm2 (i.e., square root of compressive strength between 3.97 and 5.73), a less modulus of elasticity was exhibited by RAC by 2.72% - 16.7% compared to NC with alccofine and without it. The results arrived at, is in alignment with previous studies, which inferred that the recycled aggregate concrete tend to exhibit low modulus of elasticity compared to normal concrete by about 16%-20% [21]. This is attributed to the fact that the recycled aggregates possess heavy uncompacted void content compared to natural aggregate, thus resulting in low modulus of elasticity [28]. The ITZ factor, between the cement paste and aggregate, creates a negative impact on the modulus of elasticity of concrete. However,this can be improved by filling the crack and pores of the recycled aggregate.

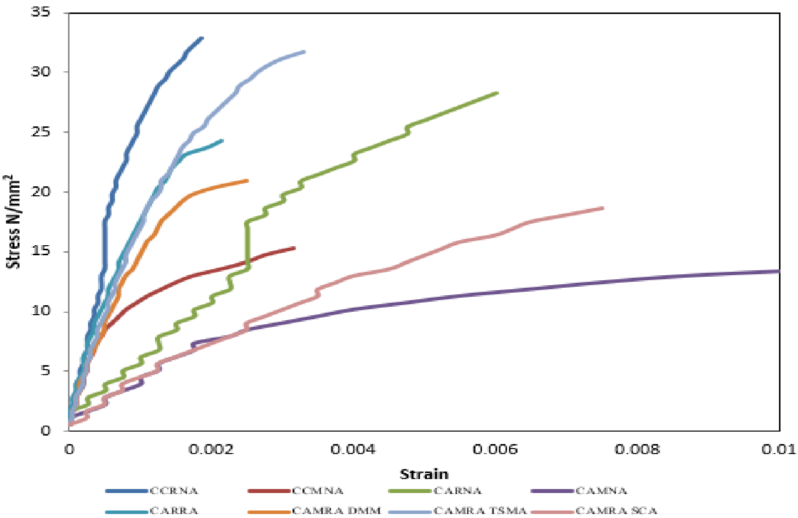


Figure 3. Modulus of elasticity of recycled aggregate.

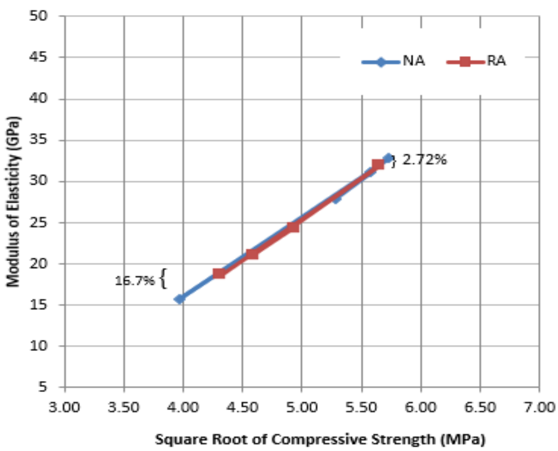


Figure 4. Relationship between modulus of elasticity and compressive strength of concretes at 28 days.

Figure 4 infers a lesser modulus of elasticity for RAC with alccofine (EAR) by about 10% compared to normal concrete (ENC) through the trend line equation (1) on normal concrete and RAC. This outcome eventually leads to the development of an empirical equation to predict modulus of elasticity for the recycled aggregate with alccofine and without it, against the normal concrete.

EAR= 0.90ENC (1)

Here, ENC denotes the normal concrete's modulus of elasticity i.e., 5000*sqrt(characteristics cube strength), according to IS 456 2000whereas EAR corresponds to modulus of elasticity of RAC with alccofine.

3.4 EFFECT OF ALCCOFINE IN MODULUS OF RUPTURE OF RECYCLED AGGREGATE

Figure 5 shows the flexural tensile strengths achieved by the recycled aggregate concrete with alccofine and without it, against the normal concrete. The addition of alccofine and mixing techniques helps the recycled aggregate to have higher flexural strength than the normal concrete.

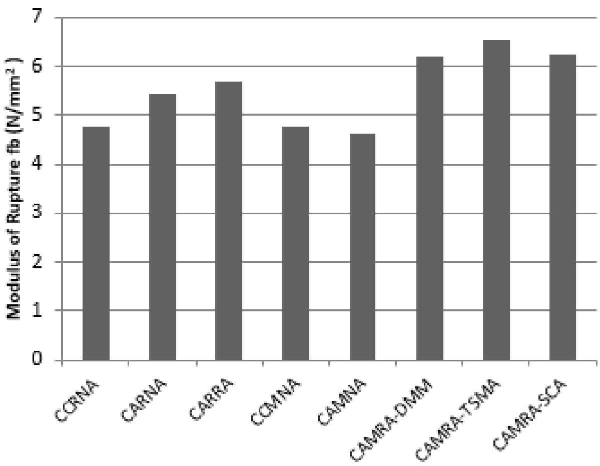


Figure 5. Modulus of rupture of normal and recycled aggregate concrete.

3.5 MICROSTRUCTURAL ANALYSIS

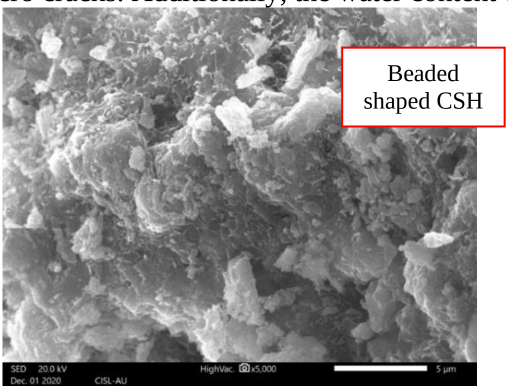
Figure 6 is a SEM photograph displaying the normal aggregate and the recycled aggregate concrete mixes with varying CSH formation. One can observe from the figure, 6(a) and 6(b) that the CSH gel, attained from the control mix, is highly rocky dense after 28days of curing period. Figure 6(c) shows that the CSH gel contains high number of pores and ettringite (needle-shaped structures) in structureafter 28days of curing. This phenomenon confirms that they show poor resistance to carbonation attack in durability point of view[29]. Figure 6(e) portrays the irregular as well as distorted flabellate and beaded shape CSH gel for CARRA mix, which occurred as a result of whole replacement of NCA with RCA. Figure 6(d) and 6(f) clearly shows the presence of alccofine and FA particles in addition to ettringite. The modifications in CSH gel shapes document the occurrence of add-on reactions of hydrated products with alccofine, as thick clouds of CSH validate the advantageous effect of alccofine in making a highly-condensed state concrete mix for improved compressiv d resistance to carbonation.

Dense rocky shaped CSH

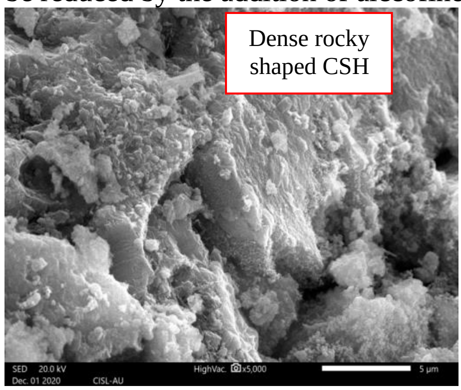
4. Conclusion

The following conclusions are drawn from the results achieved in this experimental investigation.

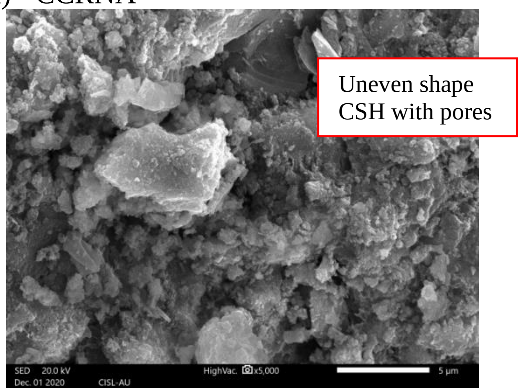
1. Alccofine can also be used alike fly ash, GGBS, silica fume etc. to enhance the strength of the recycled aggregate concrete because of their PSD and filling up of micro and macro cracks. Additionally, the water content can be reduced by the addition of alccofine.



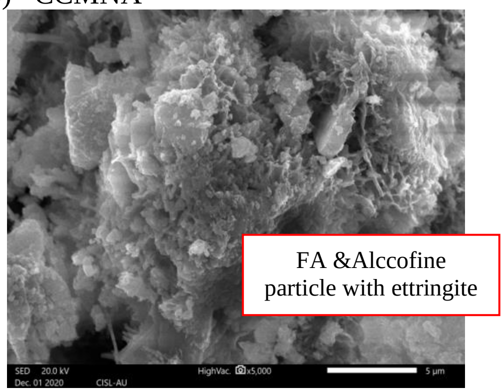
(a) CCRNA



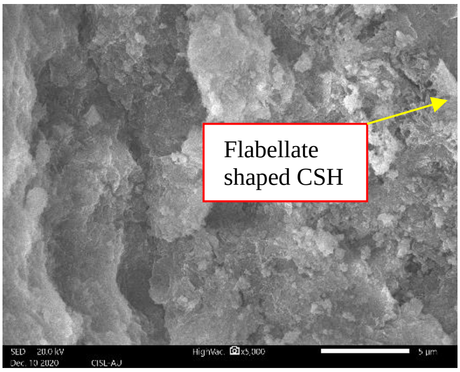
(b) CCMNA



(c) CARNA



(d) CAMNA



(e) CARRA

(f) CAMRA

Figure 6. SEM Photograph

2. The mechanical property of RAC can be improved by using techniques TSMA, DMM, and SCA.

3. The mixing techniques increased both modulus of elasticity as well as modulus of rupture by stuffing the cracks and pores found in the recycled aggregate concrete.

4. It is observed that the modulus of elasticity of RCA concrete is 90% of the NCA concrete.

5. The ITZ and concrete matrix of RAC can be improved by mixing techniques and the addition of alccofine which is evident from microstructure analysis.

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