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Experimental Investigation Of Glass Waste Suitability For Green Concrete

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ABSTRACT

Cement Industry in India is the 2nd largest Industries in the world with an installed capacity of 410 million metric tonnes per annum in 2024.The amount of natural coarse aggregate used by construction industry is approximately may be taken as 1100MT per year and is a very huge quantity of this natural materials. It is worth mentioning that the construction and demolition (C&D) waste from civil engineering works like buildings, pavements, and roadways are increasing exponentially which creates a lot of difficulty in the mining activities. It is expected that the recycled aggregates obtained from C&D waste like crushed concrete, ceramic waste (tiles, bricks), glass, and plastics, may be recycled in concrete which in turn brings sustainability in construction industry as well as sustainable use of natural materials. Indian policymakers are beginning to pay more attention to the management of construction and demolition waste(C&DW).

Keywords: *Normal Concrete, Reused Concrete, Reused Coarse Aggregate, Reused Fine Aggregate*

1. INTRODUCTION

If reused aggregate or glass aggregate may be used in fresh concrete production, it will not only save our planet from depletion of natural aggregate but also save our natural hills and rivers at large instead of dumping and in landfill engineering for filling of low lying and marshy lands and can gives rise to a secondary economy known as circular economy in construction. Although the concrete prepared with reused aggregate does not gain wide applications in structural concrete but it will definitely be used in non-structural concrete like pavement, walkways and manufacturing of paver blocks for low density and low axle load vehicular traffic roadways including major district road. Construction and demolition waste (C&DW) management is now one of the big revolution going to come in Industry 4.0 on sustainable construction materials. The method used in this study is to give a material flow analysis approach. Estimates based on different assumptions revealed that India's 2024 C&DW generation ranged from 150 to 500 million tones. These findings indicate a significant disparity compared to the officially reported figures. Given that India's rural population is still more than twice as large as its urban population, even while per capita trash generation in rural areas is lower than in urban areas, rural areas as a whole produce more waste than urban areas. Based on estimates, recycling formal C&DW can lead to saving approximately 2-8% of natural minerals, such as sand and aggregate, in urban regions. Depending on the destruction method used, significant amounts of garbage are produced when any infrastructure is destroyed in a relatively shorter amount of time. Typically, 12% cement and 80% aggregate make up the mass of standard concrete. According to this, we must consume 10 to 11 billion tonnes of sand, gravel, and crushed rock annually to produce concrete. Forested areas and river site ecology are negatively impacted by the mining and transport processes necessary to produce huge amounts of aggregate. Thus, efficient waste management is required in this situation. The requirement for proper construction waste management is necessary while considering India's future infrastructure plans.

Recycled aggregate combined with other organic materials including cement, water, fine aggregate, and other ingredients to create reused concrete (RC). Using synthetic materials as aggregates in place of natural ones is a preferable option given the benefits it offers in comparison to the cost and economy. Although though the West and the far East, such as Japan and Korea, are increasingly using recycled coarse aggregate to make new concrete, there is still a fair amount of ignorance about the possible uses of this aggregate in India. India is the 2^{nd} largest purchaser of cement in the world.

1.1 Background Knowledge:

Sands and rocks from alluvial rivers are frequently used to distribute concrete. Because the materials are widely available and reasonably affordable to process, they are frequently used. Also, due to their physical characteristics, such as shape, gradation, and so forth, they produce excellent concrete. Over a long period of time, these deposits were often organized according to standard method. The utilization of these deposits is excessive. There is a sand scarcity. Sand mining is widespread, and it poses ecological problems by consuming groundwater. Some state governments oppose mining for the following reasons: (I) Earth-damaging mining of streambed sand. (ii) The level of the ground water is impacted by the digging of deep trenches in the stream bed. (iii) The nearby lands erode as a result of the excess of sand lifting. The well-foundation of the bridges is frequently exposed as a result of the excessive rising of sand surrounding the substructure, endangering the safety and longevity of the bridges.

1.2 Understanding of problem definition by literature Review:

Traditionally, waste from construction and destruction has been considered valueless material within a linear economic model, resulting in its disposal in landfills, so various nations are investigating novel strategies to lessen excessive consumption and improper handling of finite resources as a result of a growing recognition of the significance of sustainability and resource management[1]. To address these difficulties and alleviate uncertainties related to implementing circular Economy (CE) model in the building and demolition debris industry, there remains an urgent requirement on behalf of a comprehensive international framework and practical guidelines[2-3]. A study was conducted to evaluate how concrete performs when reused aggregates of varying dimensions and percentages are incorporated[4]. Moreover, the researchers prepared high-strength concrete mixtures to explore the concept of internal curing. The mixtures underwent tests to assess their mechanical properties and durability[5-6]. The results indicated that incorporating reused aggregates into concrete, up to a specific replacement percentage, did not have a detrimental effect on the concrete's properties. M25 grade concrete was chosen to study and examine the mechanical properties of reused aggregate concrete[7]. They explored the effects of incorporating fly ash and GGBS (Granulated blast furnace slag) at different replacement ratios in reused aggregate concrete[8]. The researchers noted that when 20% of the cement was replaced with fly ash, the compressive strength, modulus of rupture, and workability characteristics of the concrete improved[9]. However, as the replacement of natural coarse aggregate (NCA) with reused coarse aggregate (RCA) increased, the compressive strength and modulus of rupture of the RCA concrete decreased[10]. It was also observed that the water absorption of reused aggregate increases initially, but decreases with a larger maximum size of the aggregate[11-12]. In a study conducted it was also discovered that concrete made with unsaturated reused aggregates showcases lower densities in comparison to normal concrete, despite a decrease in the effective water/cement ratio [13]. When incorporating 20% reused aggregates, the density values are approximately 5% lower compared to the density of control concrete [14-16]. According to the experimental findings, there is a 15% and 25% increase in compressive strength after 7 and 28 days, respectively, when 20% of the fine total is replaced with unused cut glass [17]. Glass that has not been used can be used to replace up to 30% of the total fine [18]. The split tensile strength falls with increasing glass content. In addition to achieving an economical blend, we can simultaneously solve the disposal issue [19-20]. We can preserve natural resources, particularly river sand, by employing glass. Experiments conducted also demonstrated that the modulus of rupture in concrete is moderately affected by the substitution of reused glass aggregate (RGA) [21-24]. When RGA was substituted in proportions ranging from 15% to 50%, the modulus of rupture experienced a decrease of only 13% [25-26]. However, other literature sources have reported that the flexural strength of RGA concrete can decrease by up to 10%. In the research, it was also investigated the influence of super plasticizers on the mechanical characteristics of concrete containing reused aggregates in comparison to traditional concrete [27-29]. The researchers discovered that the inclusion of super plasticizers assisted in mitigating the reduction in compressive and splitting tensile strength caused by the utilization of reused aggregates, with less effectiveness compared to their use in traditional concrete [30]

2. SELECTION OF TEST METHODS AND PARAMETERS OF STUDY:

Cement:

In this research, we used regular portland cement with a 43-grade, meeting the specifications outlined in the IS code 12269-1987. The specific gravity of the cement was found to be 3.12.We gathered cement samples following the IS: 3535-1986 standards and tested them according to the relevant specifications of IS 4031 – 1996. The physical properties and chemical makeup of the cement are detailed in Table 1

TABLE 1: Testing of cement

Tests conducted	Results obtained	Values as per IS	IS code
Cement type	Opc-43		8112
Specific Gravity	3.12	<3.15	2720- part3
Fineness test	8%	<10%	4031(part1)-1988
Standard consistency	40%		4031(part 4)-1988
Soundness test	6mm	<10 mm	4031(part 3)-1988

Time of initial setting	85 min	>30 min	4031
Time of final setting	300 min	< 600 min	4031

Natural Fine Aggregate:

In this study, when we talk about fine aggregate, we mean the particles that fall within the range of 4.75 mm to 150 microns. We used river sand for our study, and it meets the standards set by the Indian Standard 383-1970. We checked the physical properties of the river sand using the guidelines from IS 2386 (Part III)-1963 (IS 1963). The sand we used is classified as Zone-I based on its characteristics. The specific gravity and fineness modulus of the sand were found to be 2.65 and 3.29, respectively. The sieve analysis results of the natural fine aggregate are presented in Table 2, which indicates the distribution of particle sizes in the river sand

TABLE 2: Analysis of fine particles using a sieve

IS sieve(mm	Weigt Retained(kg)	Cumulative weight retained(kg)	Cumulative% retained	% passing
10	0	0	0	100
4.75	2	0.1	0.1	99.9
2.36	225	11.25	11.35	88.65
1.18	1006	50.3	61.65	38.35
600	231	11.55	73.2	26.8
300	323	16.15	89.35	10.65
150	83	4.15	93.5	6.5
pan	130	6.5	100	
Total			W= 329.15	

FINENESS MODULUS=W/100=3.29

Weight of the sample taken=2000g

Percentage of weight retained on 4.75mm seive

=(2/2000) x 100=0.1%

Natural Coarse Aggregates:

Crushed coarse aggregate that was readily accessible locally and met the requirements of Indian Standard 383-1970 was used in the trials. The coarse aggregate's particle size distribution complied with IS (2386 part I) specifications. The coarse aggregate's nominal size allowed it to pass through a 40 mm screen and remain on a 10 mm sieve. The coarse aggregate's specific gravity was found to be 2.78. According to IS 2386-1963 (Part IV) criteria, the mechanical characteristics of both natural and recycled aggregates were assessed. Table 3 shows the distribution of particle sizes based on the sieve examination of the natural coarse aggregate.

TABLE 3 : Analysis of natural coarse particles using a sieve

IS sieve (mm)	Retained Weight (kg)	Cumulative retained weight (kg)	Cumulative% retained
40	0	0	0
32	1.2	1.2	24
20	1.8	3	60
16	0.5	3.5	70
10	1.5	5	100
4.75	0	5	100
Total	5		354

Cumulative% retained at 32mm sieve = 1.2/5 x100%=24

Fineness Modulus=354/100=3.54

Weight of the sample taken=5kg

TABLE 4: Results of various treatment techniques for the properties of natural aggregate (NA) and reused aggregate (RA)

Test conducted	Natural Aggregate	Machine mixed reused aggregate RA(AT)	Hand mixed reused aggregate RA(CST)	Chemical mixed reused aggregate RA(CT)	Values as per IS code
Specific gravity	2.78	2.47	2.53	2.57	2.5-3.0
Absorption of water(%)	1.21	4.31	5.45	6.34	< 2%
Impact value(%)	9.65	13.45	15.23	16.15	<45%
Crushing value(%)	23.48	25.1	27.89	26.67	<30%
Abrasion value(%)	14.54	19.48	22.89	24.78	<50%

Water:

In the study, tap water was used as the water source for the experiments. The tap water was consumable and free from salts or synthetic chemicals. It was readily available at the material testing laboratory in our departmental research lab.

3. PRESENTATION & INTERPRETATION OF RESULTS & DISCUSSIONS:

Measurement of Workability by using the Slump Test:

Despite being straightforward, the test needs to be performed precisely because any failures could result in serious problems. For different concrete mixtures, the methods of sampling and analysis of concrete (IS:1199) were used to evaluate the workability by slump cone. Slump test results were measured in millimeters. In order to make concrete mixes, 10%, 20%, and 30% of reused coarse aggregate (RCA) and reused fine aggregate (RFA), both with and without treatment, were substituted. RC(AT) is the label for reused concrete that has been abrasion-treated, while RC(CST) is the label for reused concrete that has been reused with aggregate that has been treated with cement slurry.

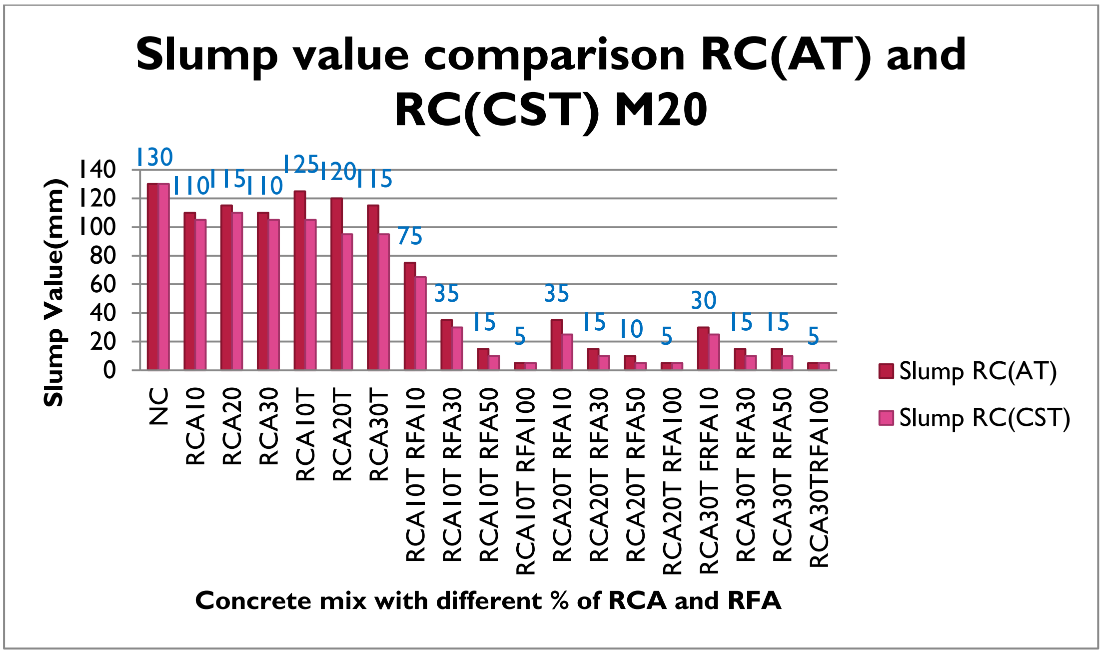

Figure 1: Slump value

Test of Compaction Factor:

Concrete's compactness, a critical component of workability, is measured by the compaction factor test for both fresh and dry concrete. It is most suitable for laboratory conditions. Figure 2 shows the compaction factor values for reused concrete (RC) with various percentage of reused coarse aggregate(RCA) and reused fine aggregate (RFA). The compaction factor values decrease with higher percentages of fine recycled aggregates, resulting in a very stiff mix.

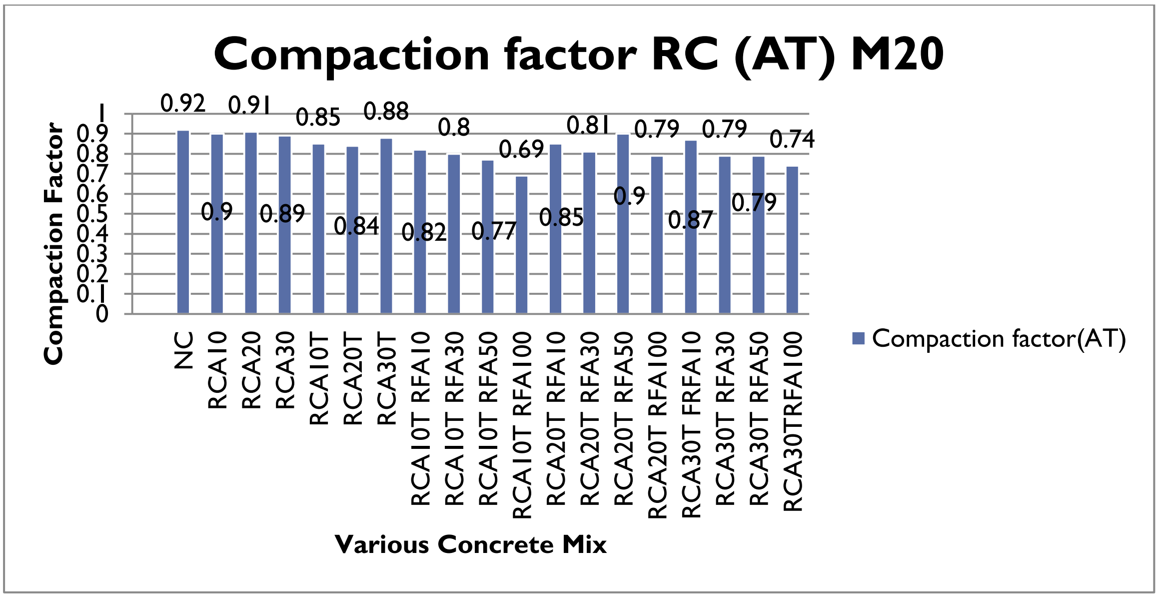

Figure 2: Compaction factor test

Calculating Reused Aggregate Concrete's Compressive Strength:

A compression machine with a 2,000 kN loading capacity was used to measure the compressive strength of all concrete classes in compliance with IS 516. Cube specimens measuring 150 x 150 x 150 mm were used to assess compressive strength, as seen in Figure 3. The samples after preparation, 28 days being cured in water. To examine the effects of replacing coarse and fine recycled material, 19 samples were cast for each concrete mix. When the specimens reached the test age, they were taken out of the curing tank and allowed to sit outside for ten to fifteen minutes. In order to test each specimen perpendicular to the casting face, it was then set up on the steel platen of the machine. The test was carried out in accordance with IS 516-1959 at a loading rate of 5 kN/s. The compressive strength test results are shown in figure. Cube strength was calculated as the crushing load per unit area.

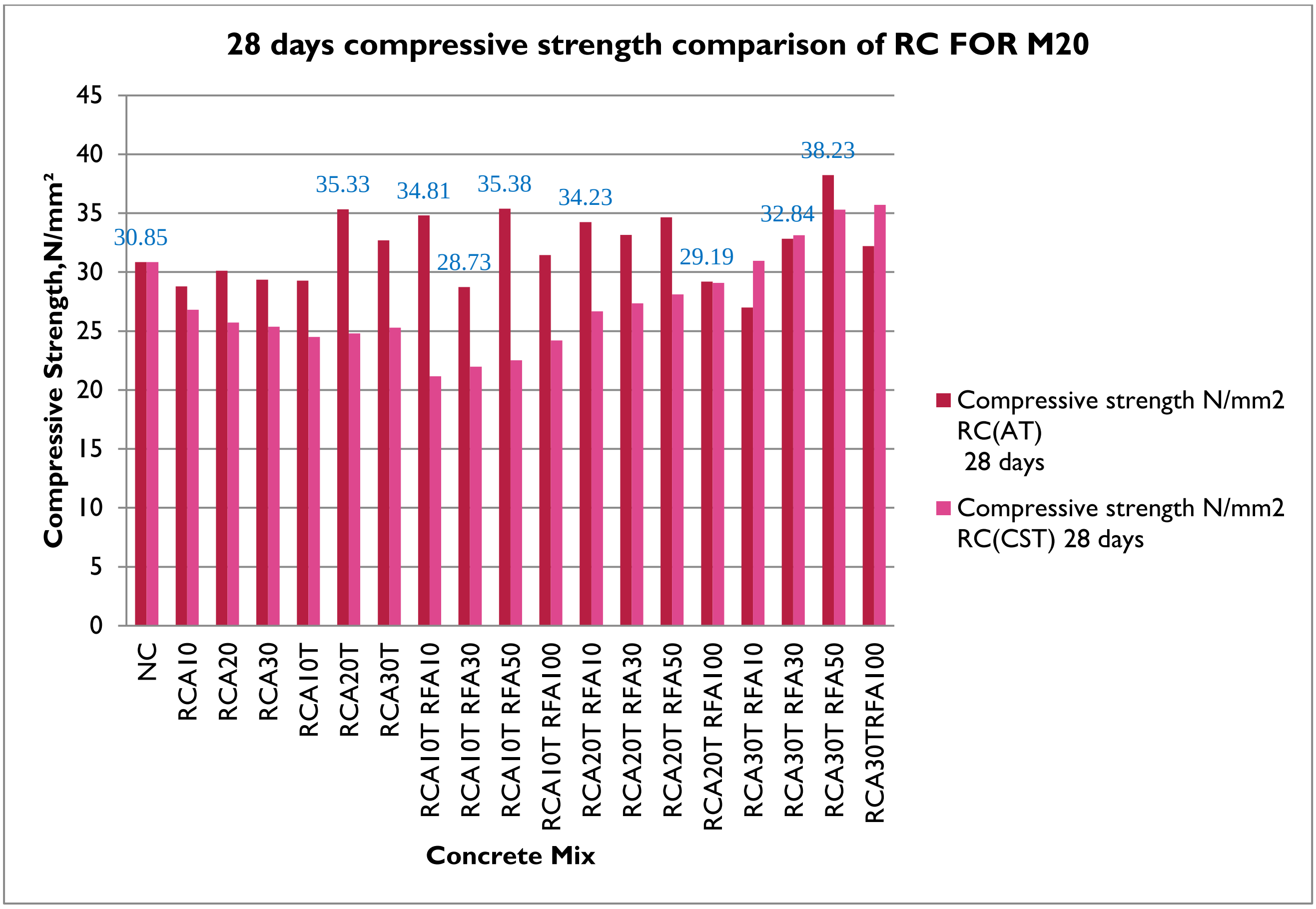

Figure 3: Compressive Strength test

Reused Concrete flexural strength and splitting tensile strength:

Tests were performed on 19 concrete mixes of M20 grade concrete with varying percentages of reused coarse and fine aggregate replacements with and without treatment.

The flexural strength test used beam specimens of 100x100x500 mm and according to IS: 516-1959 norms. For twenty-eight days, the specimens were cured in water. Beam specimens were supported on two 4.5 cm diameter rollers for the flexure strength test. By dividing the computed bending moment by the section modulus of the beam specimen, the flexural strength was determined. Split tensile strength was determined by using cylinders that were 150 mm in diameter and 300 mm in length, and the test was carried out in accordance with IS 5816.Samples were cured for 28 days, and the tensile tests were conducted using a compression testing machine with a capacity of 3000 kN.

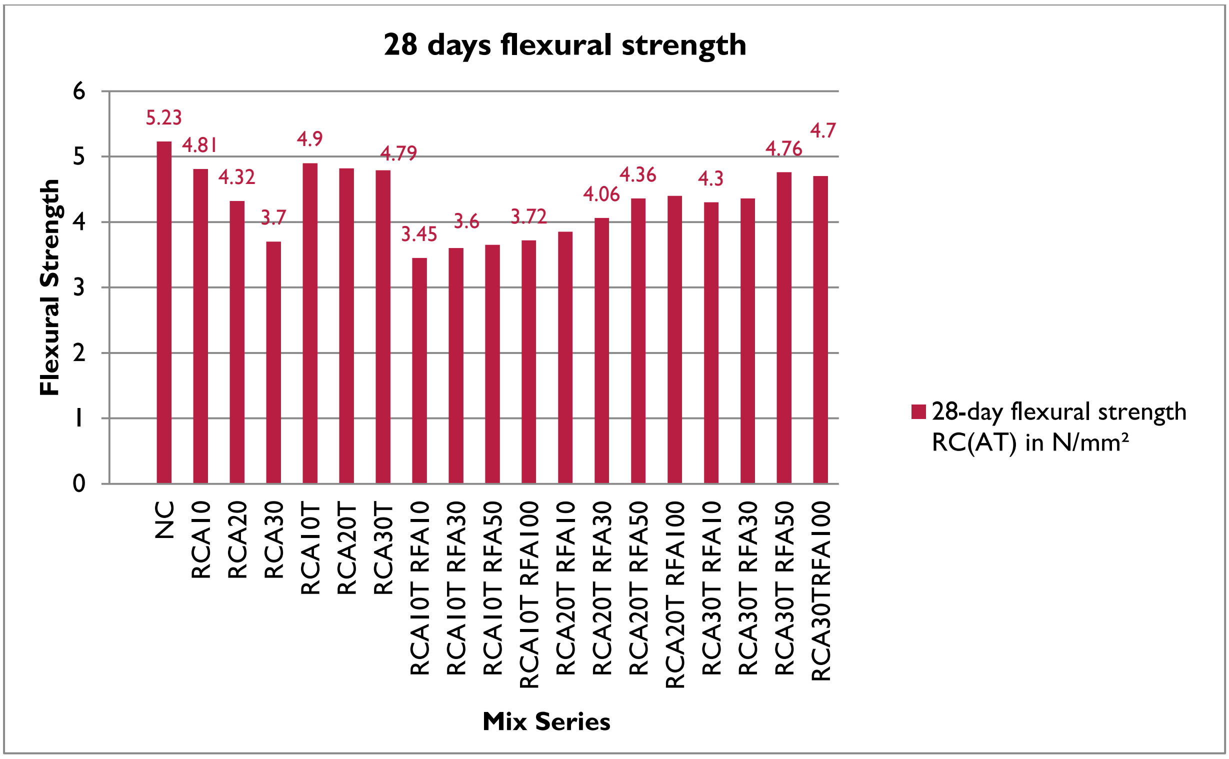

Figure 4: Flexural strength test

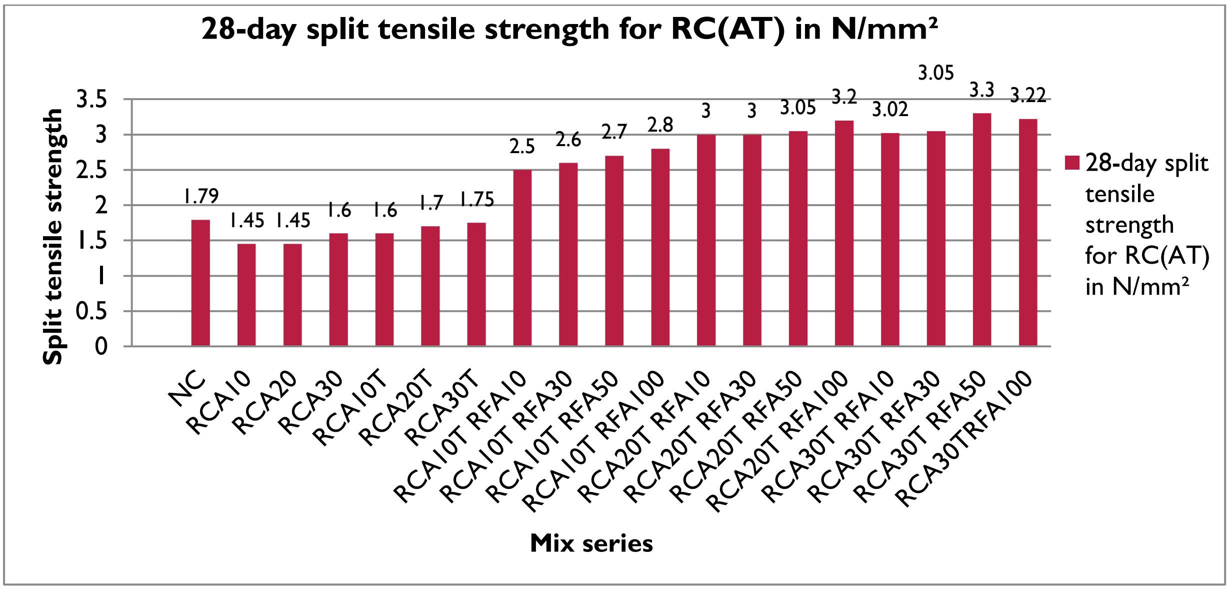

Figure 5: Split tensile strength

4. DIFFERENT CODE ELASTICITY MODULUS PROVISIONS IN TERMS OF F_{CK}:

The Indian standard code provides a relationship between modulus of elasticity of concrete and compressive strength of cube as per IS 456:2000 and the relationship is as follows:

$E_c = 5000\sqrt{f_{ck}}$

The American Concrete Institute(ACI 318) provides a relationship between modulus of elasticity of concrete and compressive strength of cylinder, which is given by the formula:

$E_c = 4734\sqrt{f_{ck'}}$

The Practice code of British (BS 8110) provides a relationship between modulus of elasticity of concrete and compressive strength of cube, which is given by the formula:

E_c=20000+0.2f_{ck}

where f_{ck} is the compressive cube strength at 28 days in N/mm², $f_{ck'}$ is the compressive cylinder strength at 28 days in N/mm², and E_c is the modulus of elasticity at 28 days in N/mm².

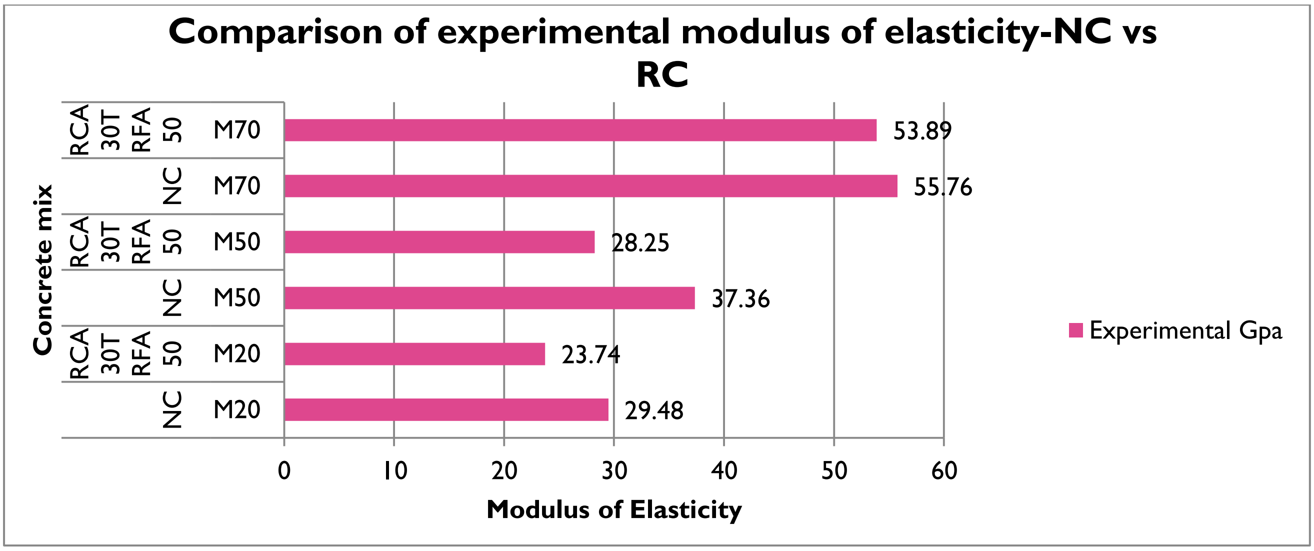

Figure 6: Modulus of elasticity of various concrete mix

TABLE 5: Comparing the concrete's modulus of elasticity using various codes

Comparing the concrete's modulus of elasticity using various codes						
			Modulus of concrete			
Sl no	Mix of Concrete	Grade of concrete	Experimental Gpa	As per IS 456-2000-Gpa $E_C = 5000\sqrt{f_{ck}}$	The ACI code $Ec=4734\sqrt{f_{ck'}}$	The British code of practice (BS – 8110) $E_c=20000+0.2f_{ck}$
1	NC	M20	29.48	27.77	24.069	20.01
2	RCA30TRFA50	M20	23.74	30.92	26.028	20.01
3	NC	M50	37.36	38.43	33.518	20.01
4	RCA30TRFA50	M50	28.25	37.79	30.782	20.01
5	NC	M70	55.76	45.76	42.034	20.02
6	RCA30TRFA50	M70	53.89	45.07	37.071	20.02

5. STRESS VS STRAIN:

The stress against strain curves for M20 grade is shown in Figures 7, which contrast reused concrete with natural concrete. As may be seen from Figure 7, which displays all experimental data, the stress-strain curves for every replacement demonstrate non-linear behavior. It was determined that the modulus of elasticity corresponded to a strain of 0.0002. Because of its brittleness and the increased water absorption of reused aggregates, the test results produced a reduce in the modulus of elasticity for reused aggregate concrete.

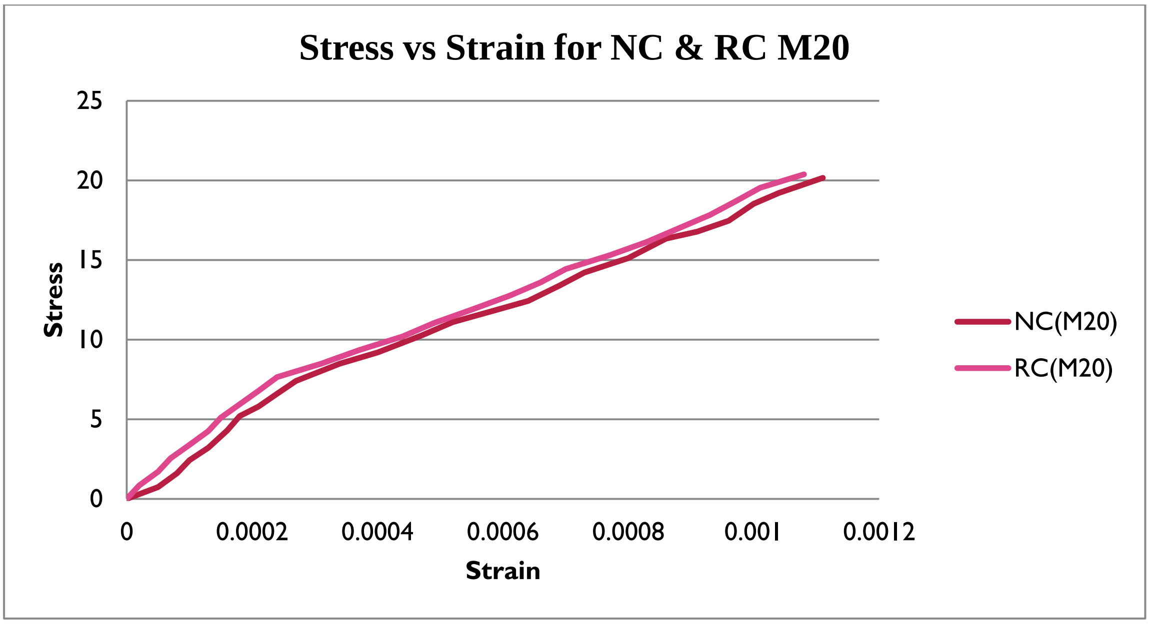

Figure 7: stress v/s strain curve

6. CONCLUSIONS

Concrete treated with abrasion, acid, and cement slurry can attain compressive strength comparable to natural aggregate concrete when 30% of the coarse aggregate is replaced with reused or recycled aggregate. Abrasion is the best treatment for removing mortar that has been applied and enhancing performance. The 28-day compressive and split tensile strength of concrete that has been mixed with 50% fine and 30% coarse aggregate is comparable to that of standard concrete (M20).

NOTE:

NC- normal concrete

RC-reused glass as concrete

RCA-reused or recycled glass as coarse aggregate

RFA-reused glass as fine aggregate

RCA10- reused glass as coarse aggregate with 10% normal coarse aggregate replaced

RCA10T-reused glass as coarse aggregate with 10% normal coarse aggregate replaced and treated or washed nicely with water

RFA10- reused glass as fine aggregate with 10% fine aggregate replaced

AT- abrasion treated

CT- chemical treated concrete with HCL solution

CST- cement slurry or hand mixed concrete

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