March - April 2020
ISSN: 0193-4120 Page No. 80 - 88

Evaluation of the Long-Term Properties of Self-Compacting Concrete using Recycled Coarse Aggregate

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Article Info
Volume 83
Page Number: 80 - 88
Publication Issue:
March - April 2020

Abstract
Recent developments of recycled concrete, with the substantial replacement of natural aggregate with recycled aggregate arising from concrete, propose a viable pathway for multiple projects while enhancing ecological standards and offering a remedy for the globally produced construction waste. The usage of Recycled Concrete Aggregate (RCA) in Self-Compacting Concrete (SCC) has the benefit of decreasing both the impact on the environment and economic costs. The research aims to evaluate the impact of recycled concrete aggregates as a fractional replacement of Natural Aggregate (NA) on the long-term properties of self-compacting concrete containing 0 to 100 percent having each sample with an increase of 25 percent coarse RCA. In order to improve the mechanical properties of SCC so that it can be applied in beam-column joints, the present study was carried out using reinforced concrete. Porosity metrics are analyzed in regards to the mechanical properties test outcomes where the distribution of the pore radius and the concrete thickness were investigated at the ages of 7, 14 as well as 28 days. Utilizing waste and recycled materials onto concrete not only has a lasting benefit yet additionally provides greater resilience towards exceptional situations faced by concrete structures, including fire, that induces significant concrete damage.In order to compare the reactions of concrete to higher temperatures at different ages, a specific metric has been adopted that reflects the cumulative region under the proportional residual strength curve for compressive and flexural after exposure to varying temperatures ranging to 800oC.The silica-fume obtained as industrial by-product activated by chemicals concentrated on sodium or potassium assists in the forming of the structure like porous foams and might be appropriate as compact and minimal-cost materials for potential insulating purposes. In aspects of porosity, thermal and acoustic insulation properties, the structures were characterized.

Article History
Article Received: *24 July 2019*
Revised: *12 September 2019*
Accepted: *15 February 2020*
Publication: *12 March 2020*

Keywords: *Recycled concrete aggregate, Self-Compacting Concrete, Beam-column joints, Long term properties, Porosity, Fire resistance, Thermal and acoustic insulation.*

1. Introduction

One of the most congested regions of reinforced concrete constructed frameworks is the beam-column joints; the setting of concrete and appropriate compaction in these areas is therefore significantly complex. It provides a specific usage of self-compacting concrete that can flow with no requirement for vibration via any corner of the extensively reinforced region. Thus, rather than traditional concrete, self-compacting concrete can be employed in beam-column joints. For a green, renewable and revolutionary future, various resources are becoming a requisite. (Kisku et al., 2017) reviewed hundreds of RCA papers on the subject and reported that the usage of mineral admixtures might improve the qualities of recycled concrete aggregates. More research on the application of alternative waste materials such as cement replacement materials (CRMs) and RCA's long-term behaviour with regard to mechanical and durability properties were suggested. RCA's utilization as a Natural Aggregate substitute has been widely examined, yet only certain research has implemented RCA's principle of self-compacting concrete (Rajhans et al., 2018). The action of recycled aggregate concrete after exposure to high temperatures can be assumed to reduce the risk of volatile spray and to improve the residual mechanical properties of the natural aggregate concrete analogy (Laneyrie et al., 2016). It is acknowledged that concrete fracture properties are foundational aspects in structural design and safety evaluation, particularly for large-scale structures. As noted by (Bordelon et al., 2009), evaluating compressive strength and tensile strength alone would not provide a clear understanding of structural reliability owing to the interplay of material conduct, early cracks, and structural geometry.So it is noted that in a defined structural framework, the concrete fracture properties will offer deeper information about the material's potential load carrying ability. Since SCC uses a large quantity of fine powders together with chemical super-plasticizers, it has a greater density of packaging compared to conventional concrete. Furthermore, due to water vaporization at high temperatures, the interior pore stress could be enhanced and this could raise the probability of concrete spilling if subjected to fire. Therefore; SCC typically has reduced fire resistance compared to traditional concrete. Because SCC is a recent product, its fire resistance has only been investigated for a limited time (Kalifa, 2000).Compact alkali-activated binders could be produced including various methods; using hydrothermal methods for achieving autoclaved aerated concrete through alkaline activation of metakaolin and fly ashes. Foamed buildings can be developed utilizing appropriate solvents; such a process has been used to manufacture durable alkali-activated slag panels incorporated with fibrous substances and is employed for acoustic insulation (Zhao et al., 2010). Paired with the prospect of producing lightweight structures, the thermal tolerance of alkali-activated materials has contributed to the application for a variety of acoustic insulation and fire-proofing technologies.

2. Objectives of the Research

The need to eliminate these wastes without polluting the environment is becoming time-critical due to the advancing everyday quantity of building waste. The principle of the waste materials being used in construction is a massive leap not only to eliminate the waste as well as to incorporate it into construction,it, therefore, adds to the improvement of the concrete properties. The research's intention is to evaluate the outcome of SCC's long-term performance under compressive loading with the properties of traditional concrete.

3. Experimental Investigation

3.1 Materials

The Ordinary Portland Cements (Grade 53) has been considered throughout the preparations in compliance with IS12269:1987. The specific gravity, surface area, and 28-day compressive strength were 2.68, 380 m2/kg and 56.6 MPa respectively. Concerning raising the cumulative content of SCC, the silica fume has been acquired from Elkem Company with a specific gravity of 2.3. The river sand may be regionally available for fine aggregate use. The natural aggregate obtained from the local quarry was compressed basalt of an average size of 12 mm. The recycled concrete aggregate included in the evaluation was obtained from the demolished structures nearby with an optimum size of 12 mm. In order to account for the impact of greater levels of recycled aggregate water absorption, the aggregates remained

March - April 2020
ISSN: 0193-4120 Page No. 80 - 88

submerged in the water for around 24 hours and cured thoroughly. The module was evaluated as per IS 383-1970. Table 1 lists the physical properties of the aggregate. A multi-carboxylic-ether-based polymer admixture was the super plasticizer used for this evaluation.

Table 1: Physical Property of NCA and RCA

Characteristics	RCA	NCA
Specific Gravity	2.14	2.68
Water Absorption	5.32	1.25
Bulk Density	1234	1632
Impact Value	9.57	18.25
Fineness Modulus	5.85	6.5

3.2 Fresh state Properties

Flowability of the SCC modified with recycled aggregates is determined by conducting slump flow and t_{500}time measures without any obstacles. The consequence is proof of the filling ability of the self-compacting concrete. A slump flow test is a responsive check that has been typically defined as the main test to all SCC that reasonably the requirement matches the quality of fresh concrete.The time of the T500 is indeed a function of the flow rate and the viscosity of the SCC. In SCC test mixes, L-box, J-ring and V-funnel tests are performed. These tests are necessary to access the SCC mix's passing ability. SCC's viscosity and filling capability were evaluated by performing V-funnel testing on modified SCC mixtures using recycled concrete aggregate. The results are quantified in table 2.

Table 2: Fresh state Properties

MIX ID	Fresh state test				
	Slump flow		J-ring	L-Box	V-Funnel
	D (mm)	T_{500} (Sec)	(mm)	(mm)	(Sec)
NSCC	719	2.01	7.2	1.0	8.30
RCA1	679	2.20	7.6	0.96	8.91
RCA2	654	2.95	7.8	0.94	9.21
RCA3	649	3.26	8	0.86	9.46
RCA4	638	3.75	8.8	0.84	10.21
RCA5	620	3.95	9.6	0.81	10.88

1.3 Hardened State Properties

SCC samples are fabricated leveraging cube molds to evaluate the properties of compression, split tensile and flexural strength. Curing period of the specimen is 28 days after that the load has been progressively distributed over the samples through compression testing machine and the measurements are tabulated in table 3. Compressive, split tensile and flexural strength tests are conducted in accordance with IS 516 (1959). The hardened state test outcomes for the 28 days cured samples are exhibited in figure 1. Results show that the addition of recycled concrete waste reduced mechanical characteristics significantly.

Table 3: Hardened state Properties

MIX ID	Hardened state test		
	Compressive strength (N/mm²)	Flexural strength (N/mm²)	Split tensile strength (N/mm²)

	7days	14 days	28 days	7days	14 days	28 days	7days	14 days	28 days
NSCC	18.52	24.89	37.65	2.63	3.23	3.69	1.98	2.67	2.99
RCA-1	17.83	21.29	34.53	2.49	2.86	3.38	1.81	2.44	2.88
RCA-2	14.79	18.99	28.26	2.42	2.69	3.26	1.77	2.32	2.76
RCA-3	11.69	17.97	27.23	2.26	2.66	2.99	1.64	2.26	2.69
RCA-4	11.21	17.61	25.47	2.13	2.43	2.67	1.45	2.12	2.53
RCA-5	10.26	17.26	24.13	1.99	2.18	2.49	1.31	2.01	2.34

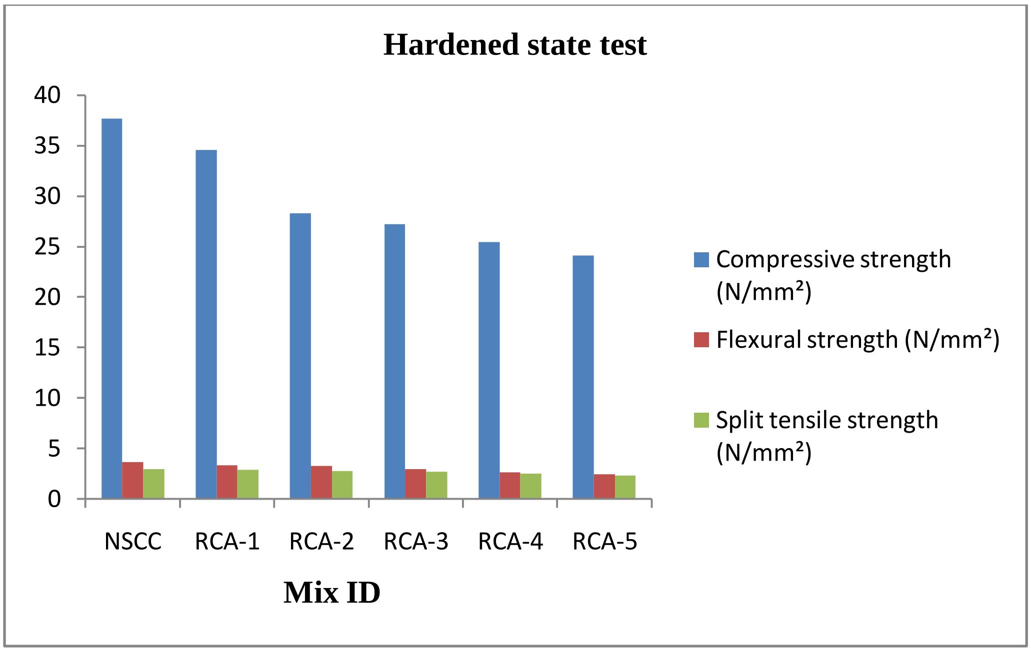

Figure 1: Result of Hardened sample for 28 days

1.4 Beam Column Joint Specimens Test Setup

The study of the behavior of the beam-column bonding is shown in three specimen forms named RCA1, RCA2, and RCA3, with SCC's assistance, the replacement of natural aggregates by recycled concrete aggregates by 25%, 50% and 75% was achieved. Likewise, such RCA specimens are strengthened with steel frameworks and confined to test. Joints with 220x220 mm have been designed.

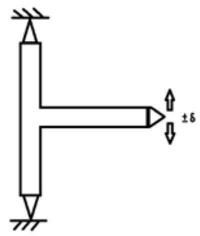

Figure 2: Representation of the Beam-column joint (T- Section) during the test

Two pins at the top and bottom ends of the column restricted the beam-column joint and vertically preloaded the column at 200 kN to represent a test in Figure 2.

March - April 2020
ISSN: 0193-4120 Page No. 80 - 88

The joint thus held about the same loads it would have borne if it were used in a reinforced concrete frame. Primarily, a natural-aggregate concrete with SCC (NSCC) beam-column joint has been evaluated. Likewise, the RCA (Recycled-Aggregate Concrete), RCASF1, RCASF2, RCASF3 (Reinforced Steel Samples) specimen was loaded, and the related yield displacement, ultimate failure load, and peak displacement are shown in Table 4 is evaluated. The study of the load /displacement curve in Figure 3 shows that RCA with steel construction has a significant impact on the beam-column joints ' load-carrying ability. The RCA specimen showed a decline in the load-bearing ability compared to NSCC.

Table 4: Load displacement of beam column joint

MIX ID	Yielding displacement in mm- δ_y	Ultimate load in kN P_u	Ultimate displacement in mm δ_u
NSCC	5.75	41.8	48.55
RCA	4.55	36.3	35.37
RCASF1	4.84	38.5	38.1
RCASF2	5.22	39	40.26
RCASF3	5.33	40.2	42.83

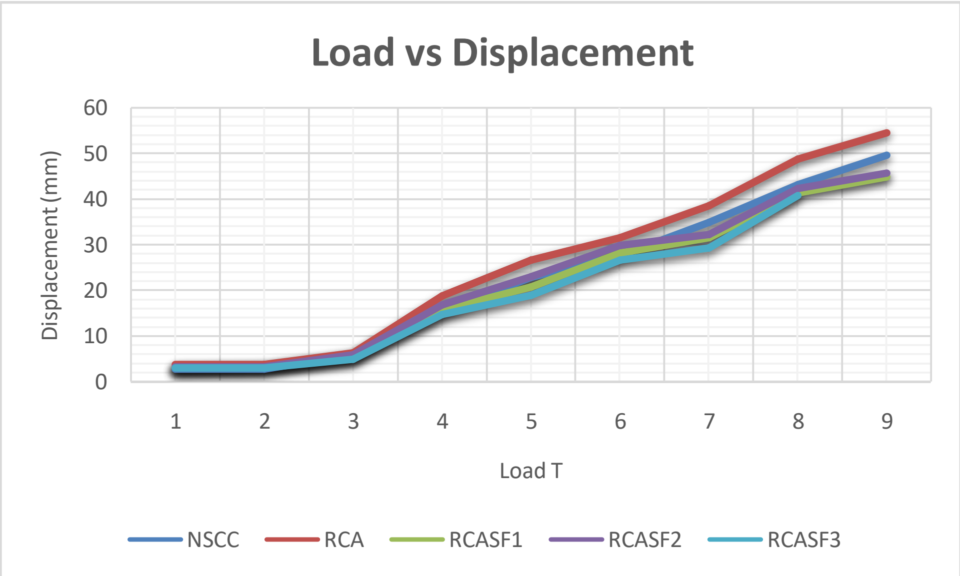

Figure 3: Load vs Displacement graph for beam column joint

1.3 Microstructural Properties: Porosity and Density

An electron (SEM) microscope that displays porosities, micro-cracks, and required interrelationships between the aggregates and mortar visually will allow NA, RCA to examine its impact on the concrete microstructure. The density declined with aninsane amount of RCA for all mixtures as RCA has a density lesser than NA. With each successive generation of recycling, the attached mortar enhances. This effect could have an influence on RCA absorption, which increased with either the amount of replacement or the generation of recycling. The porosity and density of the concrete produced are shown in Figure 4.On the basis of the rise in RCA quantities as a circular process, CT imaging can be used to examine the pore distribution and volume and to gain information into the internal structure with no need to break the sample. The results show that the pore volume and amount improved with the introduction of RCA but decreased after recycling in first generation. Nevertheless, the number of pores varies with the same total pores in cases of RCA25 and RCA50. The pores of RCA25 were smaller but larger than those of RCA50. The pores density was projected to be increased by 50 percent NA being replaced by RCA but in the case of SCC, the amount of RCA replacement was almost the same as for 25 percent.

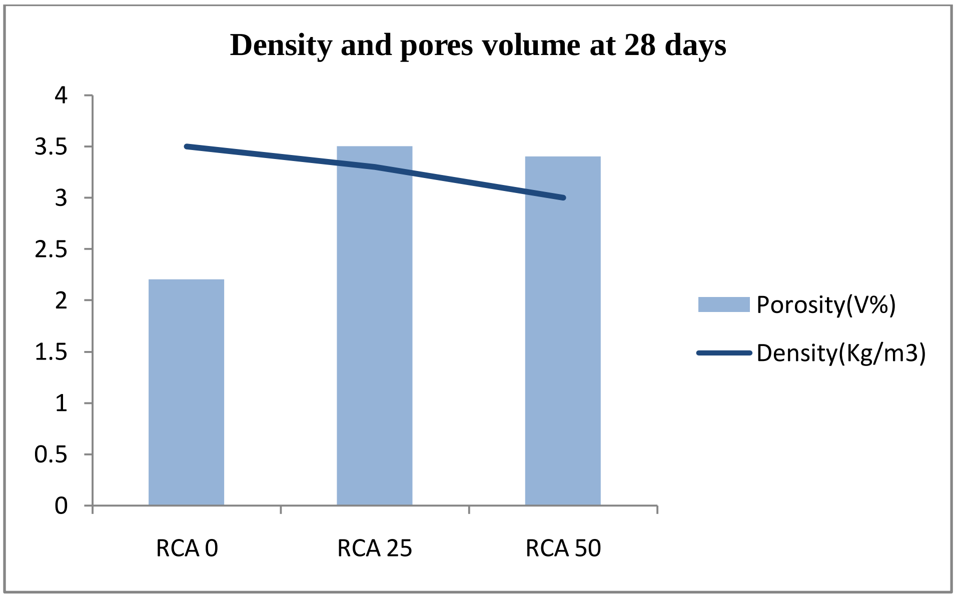

Figure 4: Results of Density and Porosity

1.5 Fire Resistance Properties

For each specimen, the heating mechanism was implemented by heating up the samples with two hours to the highest temperature, and the maximum temperatures were: 20, 150, 300, 500, 600 and 800°C. Then the specimens were left in the environment of the laboratory in order to cool them off. The temperature spectrum from 20 to 800°C is the same as the temperature range that is a real fire situation that could occur for 1 hour (Hlavicka, 2017). Figure 5 indicates that the heating curve for buildings up to 800°C is similar to standard ISO 834 fire curves.The residual mechanical properties were tested at 28 days after temperature elevation, with an effort to represent the behavior of actual structures at high temperatures. The compressive and flexural strengthswere measured individually as a function of temperature. It was calculated by measuring the total area under the 20 to 800°C relative residual strength curve.It expresses the heat resistance parameter.

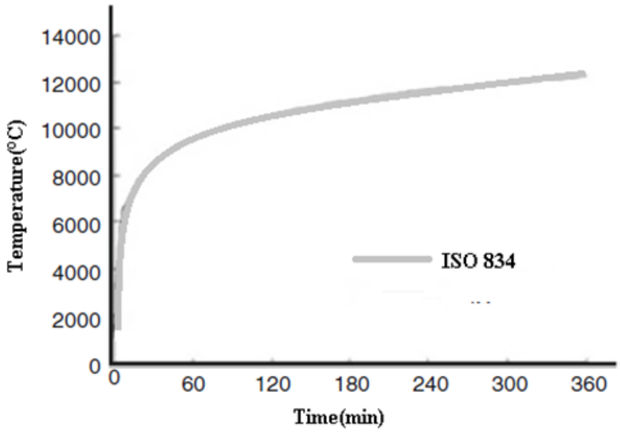

Figure 5: Standard Fire ISO 834 Curves

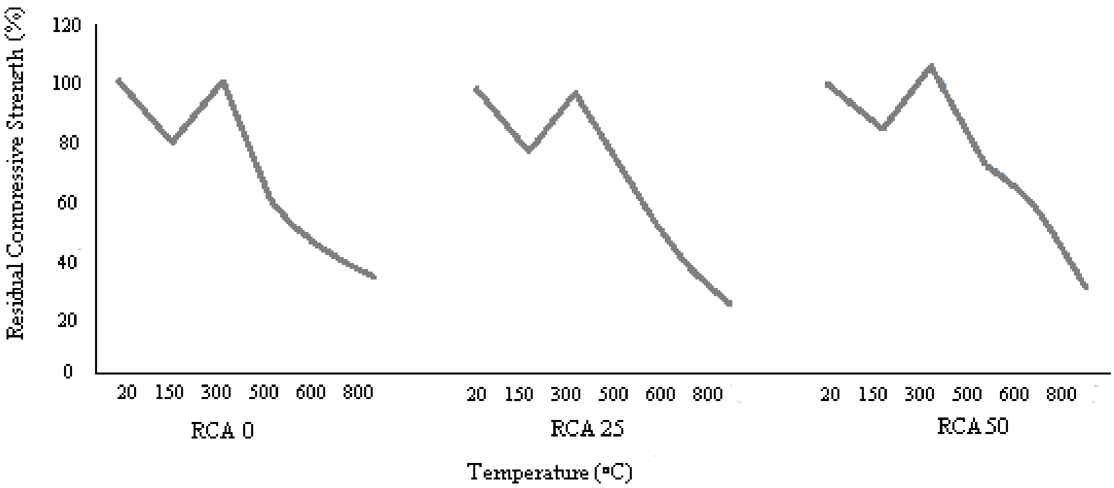

Figure 6: Residual compressive strength with respect to temperature at 28 days

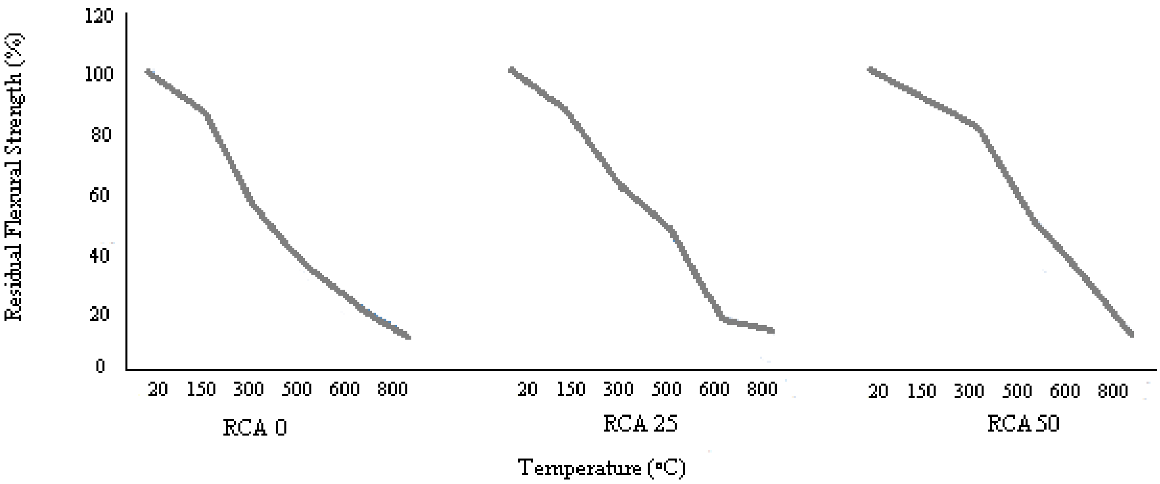

Figure 7: Residual Flexural strength with respect to temperature at 28 days

Graphical analysis shows that the compressive strength heat resistance in SCC has progressively increased with age, and this result is shown in Figure 6 that is expected owing to the

March - April 2020
ISSN: 0193-4120 Page No. 80 - 88

improvement in strength and reduction in age with water quantity. The flexural strength levels decrease slightly over time, and the drop is low and ultimately negligible, as shown in Figure 7.

1.6 Acoustic Properties

These tests the nature of the porous structure of the foams and can be used for further separation as lightweight and low cost materials if the resulting materials are found to be suitable. Tests of sound absorption were conducted utilizing the impedance tube system. The internal diameter of the impedance tube was 2.9 cm, which was equal to a high frequency of 6,400 Hz, and two quarter-inch microfones were mounted to measurements above 400Hz at distance of 2 cm. The theory, as defined in the ISO 10534-2 standard, was focused on the transfer function calculations among the two microphones. For this method, incident and reflection waves have been isolated at frequencies in the range 400–6400 Hz to evaluate the sound stress reflection coefficient R. An equation was used to calculate the sound absorption coefficient α that is ($\alpha=1-|R2|$).

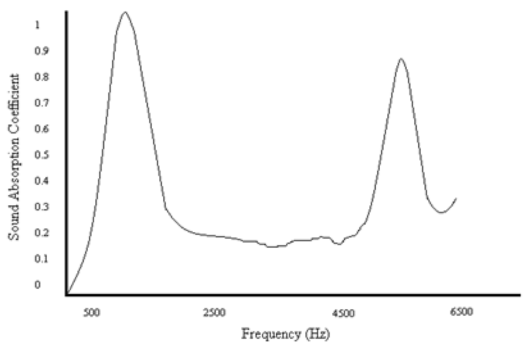

Figure 8: Sound absorption coefficient Vs frequency

The experiments were conducted on the surfaces of the cube sample. The impact of sample irregularities, especially at the edges, was kept into consideration by repeating the experiment for each formulation on three samples. Initial experiments to examine the acoustic properties of the foams were conducted on the samples. The sound potential can be measured by the sound absorption coefficient α, calculated in accordance with the frequency, as indicated in Figure 8.The acoustic absorption properties of airflow resistance, porosity and pore morphology are usually dependent on three interrelated variables. Two factors are primarily responsible for sound absorption: a loss of viscosity because of flow resistance and a heat transfer loss. The viscous failures are defined by the foam's flow resistance, also regulated by the circumstances in the smallest sections of the pore pathways (Han et al., 2003). The acoustic activity of the foams can be related to the creation of interconnected pore morphology.Nevertheless, the huge pores formed by the foaming method are bound to the pore walls by unevenly shaped and narrower pores, creating a complicated network of interconnecting air tunnels. There is still a need for further research into the acoustic properties.

4. Conclusion

In an attempt to determine the real-scale activity of reinforced recycled aggregate concrete, numerous beam-column joints were produced, after which cured in outdoors at a temperature of approximately 20°C in exchange to replicate the real circumstances of the construction site. The trial method suggested that for such properties, minimal or no adverse effect was reported at RCA consumption rates of 25 to 50 percent. The analysis revealed certain variability in regard to ordinary concrete in the RCA's properties. If NA is replaced by RCA, porosity significantly increases. The results emphasize that self-compacting properties are preserved if recycled aggregates are used and its adequate content encourages high structural properties and distributions of pores size are further affected by the content and abundance of recycled aggregates, while its influence is much more constrained relative with that occurs to recycled aggregates in conventional concrete. While considering the properties of thermal resistance, the results

March - April 2020
ISSN: 0193-4120 Page No. 80 - 88

revealed that the concrete age affects the concrete response to elevated temperatures. The compressive strength heat resistance improved with age, but the concrete acted at the age of 28 days with a distinct tendency. The heat resistance of flexural strength at the age of 28 days was not compromised or massively decreased but at the age of 28 days was not greater than 10 percent. When subjected to heat, self-compacting concrete (SCC) containing quartz powder is susceptible to spalling. With the use of additives, attempts have been made to modify the fire resistance of this type of SCC.One approach to prevent the spalling of fire is to incorporate polypropylene fibers, PPF, in the proportions of the mix which were preferred to be quite successful. The samples were subject to high temperatures and quantified their residual compressive strengths.The foam structures are ultimately fine sound-absorbing materials, particularly in specified frequency ranges, with regard to acoustic properties. However, the analysis regains perspective into that field and thus to build a framework for more experiments to determine the possible implementation of the foams in the sector of insulation.

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