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Research Article

Mechanical and durability characteristics of SCC incorporating recycled aggregate and steel slag

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ABSTRACT

This study presents a detailed investigation of the properties of self-compacting concrete (SCC) incorporating steel slag-based granulated slag aggregates (GSA) and recycled aggregates (RA) as substitutes for M-sand (MS) and natural coarse aggregates (NCA), respectively. NCA was replaced with coarse recycled aggregate (CRA) at levels of 20%, 25%, 30%, and 35% in SCC mixtures containing either MS or GSA as the fine aggregate. Cement was blended with ground granulated blast-furnace slag (GGBFS) and metakaolin (MK). The evaluated fresh properties were within the limits specified by EFNARC. The compressive strength of MS- and GSA-based SCC ranged from 24.2 to 35.9 MPa and from 27.4 to 38.9 MPa at 28 and 56 days, respectively. Increasing the curing period from 28 to 56 days enhanced the compressive strength by 3.4–13.2%. Acid immersion resulted in mass losses of 0.4–2.4% and reductions in compressive strength of 2.60–7.52%. The maximum water absorption (WA) of the SCC mixtures remained below 3%. Increasing the CRA content increased the permeability from 21.9 to 24.8 mm. No significant variations in WA, acid resistance, or permeability were observed in GSA-based SCC containing up to 30% CRA. Overall, the experimental results demonstrated that GSA-based SCC exhibited better performance than MS-based SCC.

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1. Introduction

Workability, strength and durability are the basic requirements of concrete. Due to the scarcity of natural aggregates, cementitious composites have been explored using various alternatives. RA, slag sand, ore tailing etc., have been investigated as substitute to conventional aggregate. More broadly, the valorization of industrial waste streams in construction materials can reduce landfill disposal and natural-resource consumption while supporting circular-economy objectives (Urbánek and Antoš 2026; Ünál and Canbaz 2026). The strength criteria of cementitious composites have been established using alternate aggregates as partial substitution to conventional aggregates.

However, the durability performance of alternative or RA-based composites requires detailed exploration. The durability of composites such as mortars and concrete is evaluated by carbonation, exposure to acidic and alkaline environments, efflorescence, deterioration due to surface wear, thermal resistance and alkali aggregate reactions.

Advancements in concrete technology have led to the development of self-compacting, non-segregating and highly workable composite known as self-compacting concrete (SCC). Ozawa et al. (1992) developed a vibration-free SCC. This workability SCC mitigates formation of honey comb and voids in the composite (Mehta and Monteiro 2014). SCC of grade M40 containing 20% RA (fine and coarse) resulted in an increase in compressive

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and split tensile strength by 5% and 1%, respectively (Vinay Kumar et al. 2017). As the recycled concrete aggregate content was increased in SCC, the strength decreased (Guo et al. 2020; Verian et al. 2018). However, blending cement with mineral admixture such as fly ash, silica fumes and slag from 50 to 75%, improves the strength properties (Guo et al. 2020). Such improvements are also sensitive to the type and dosage of mineral admixtures (Shaheen et al. 2025). Low impurity surface treated RA or those sourced from the precast concrete industry are suitable for producing workable and durable SCC (Verian et al. 2018; Santos et al. 2019).

Nomenclature

σ_c	Compressive strength
ADF	Acid durability factor
BPV	Binder paste volume
CA	Coarse aggregate
CRA	Coarse recycled aggregate
FA	Fine aggregate
GGBFS	Ground granulated blast furnace slag
GSA	Granulated slag aggregates
MK	Metakaolin
MS	M sand
NCA	Natural coarse aggregate
NFA	Natural fine aggregate
OPC	Ordinary portland cement
RA	Recycled aggregate
SCC	Self-compacting concrete
WA	Water absorption
ZI-LL	Zone I lower limit
ZI-UL	Zone I upper limit
ZII-LL	Zone II lower limit
ZII-UL	Zone II upper limit

Substituting sand with steel and foundry slag in concrete resulted in increased compressive strength and comparable flexural strength (Olonade et al. 2015; Sharma et al. 2017). Slag with properties similar to M-sand can be used as a substitute for fine aggregate (Thomas et al. 2019). The use of copper slag as a substitute for NFA resulted in a 10% increase in SCC performance (Gupta and Siddique 2020). The compressive strength increased by 21% when iron slag was used as fine aggregates in SCC, with a denser internal structure noted from SEM (Singh and Siddique 2016; Pham et al. 2024; Deepak et al. 2024; Khoman and Owaid 2026). Utilization of oxidizing and reducing slag obtained during manufacture of stainless steel can be used as a replacement to conventional aggregate and cement respectively. Using oxidizing slag as fine and coarse aggregate substitutes and cement blended with 30% reducing slag increased the viscosity of the mix while yielding comparable compressive strength (Sheen et al. 2016). SCC made with blended cement and slag sand resulted in a 14 – 29% reduction in compressive strength (Vageesh et al. 2026; Bala et al. 2025).

Fly ash, and silica fume blended cement based concrete with 40% RA of M40 grade exhibited improved resistance to water absorption and chloride penetration than that of equivalent concrete (Poongodi et al. 2021).

Blending 10% steel slag with Portland cement for SCC with RA exhibited superior durability in aspects of chloride penetration and carbonation resistance (Pan et al. 2019). Replacing 25% of the coarse recycled concrete aggregate had no impact on durability properties of SCC. The increased substitution of fine RA significantly decreased the resistance to chloride permeability (Sasanipour and Aslani 2020).

Effects of mineral admixtures, RA and GSA on the performance of SCC have been reported by the various researchers. However, research on their combination of mineral admixture and alternate aggregates and its influence on SCC remains limited. Thus, the current research focuses on investigating the combined influence of cement blended with two mineral admixtures, GSA as fine aggregate and CRA as a partial substitute to natural coarse aggregate, on the performance of SCC with an emphasis on the durability of SCC.

2. Research Significance

The performance of SCC is influenced by attributes such as aggregate type and its physical and engineering properties. The existing literature reveals the need for further research to holistically understand the suitability of alternate aggregate and its influence on properties of SCC. In this context, the current study investigates the combined influence of three parameters, blended cement, GSA as fine aggregate and CRA as a partial substitute for NCA. A detailed experimental investigation was carried out on the fresh, hardened and durability properties of SCC. Durability studies report the behavior of SCC exposed to acidic environment. Through experiential investigations, this study explores the suitability of CRA and GSA as an alternate source of aggregate in development of SCC.

3. Materials and Methodology

The constituent materials used in the current study were 53 grade ordinary Portland cement (OPC), ground granulated blast furnace slag (GGBFS) and metakaolin (MK) as binders. M-Sand (MS) and Granulated Slag aggregates (GSA) were used as fine aggregate, and Coarse recycled aggregate (CRA) was used as a partial substitute for NCA. The alternate fine and coarse aggregates used in the study are presented in Fig. 1.

A polycarboxylate ether-based superplasticizer (SP) was used as a water-reducing agent. The properties of constituent materials were evaluated according to the Bureau of Indian Standards, and the results are presented in Table 1 and Table 2.

GSA and MS were categorized as Zone I and Zone II fine aggregates as per IS 383 (2016). The grain size distributions of MS and GSA are shown in Fig. 2. It can be noted from the figure that the grain size distribution of GSA presented improved gradation compared to MS, leading to improved packing of GSA. The particle size corresponding to 60%, 30% and 10% finer by weight, viz., D₆₀, D₃₀ and D₁₀ of GSA were greater than that of MS.



Fig. 1. Alternate aggregates: (a) GSA; (b) CRA.

Table 1. Physical and chemical properties of binders.

Properties		OPC	GGBFS	MK	Ref
Physical	Specific gravity	3.02	2.87	2.73	IS 2720-3-1 (1980)
	Bulk density (kg/m ³)	1447	–	–	IS 4031-11 (1988)
	Fineness (%)	4	7.2	3.4	IS 4031-1 (1996)
	Normal consistency (%)	34	–	–	IS 4031-4 (1988)
	Setting time (min)	Initial	–	–	IS 4031-5 (1988)
		Final	–	–	
Chemical	CaO (%)	64	36.23	0.4–1.0	
	SiO ₂ (%)	21	35.82	60–66	
	Al ₂ O ₃ (%)	6	16.98	30–33	
	Fe ₂ O ₃ (%)	4	0.71	1	
	TiO ₂ (%)	–	–	2	
	MgO (%)	3	8.02	0.2–0.8	
	K ₂ O, Na ₂ O (%)	0.5–1.3	–	0.5–1.2	

Table 2. Physical properties of aggregates.

Properties	Fine aggregate		Coarse aggregate		Ref
	MS	GSA	NCA	CRA	
Specific gravity	2.66	2.62	2.75	2.43	IS 2386-3 (1963)
Density (kg/m ³)	1611.0	1449.5	1478.5	1308	IS 2386-3 (1963)
Fineness (%)	2.93	3.41	–	–	IS 383 (2016)
WA (%)	1.12	0.44	1.0	2.75	IS 2386-3 (1963)
Abrasion value (%)	–	–	18.7	35.2	IS 2386-4 (1963)
Impact value (%)	–	–	12.1	33.2	IS 2386-4 (1963)
Crushing value (%)	–	–	16.6	30.2	IS 2386-4 (1963)

3.1. Mix proportions and specimen details

An M30 grade SCC mix was designed with a proportion of 1:2.19:1.75 (Binder: FA: CA) as per IS 10262 (2019). A detailed flow-chart of the criteria's considered in the mix design is presented in Fig. 3. As per EFNARC (2002), the total voids, that is, air content considered in the mix design of SCC was 2% of the total volume. The binder was composed of 64.5% cement, 34.5% GGBFS and 0.6% MK (Vinay Kumar et al. 2017). The water-to-binder ratio and SP dosage were maintained at 0.43 and 0.7% respectively. Two series of SCC mixes were devel-

oped using MS and GSA as fine aggregate. In both series, NCA was partially substituted by CRA from 20% to 35% at an incremental rate of 5%. The fine and coarse aggregate compositions in SCC mixes are presented in Table 3. The aggregate to cement ratio was maintained at 3.94 with a binder paste volume (BPV) of 0.35. A total of ten mixes were investigated and the SCC mix proportions are presented in Table 3. The fresh properties namely slump flow, V-funnel, L-box, U-box, and J-ring test, were evaluated as specified by EFNARC (2002). The hardened properties of SCC constituted of evaluating compressive strength and durability tests.

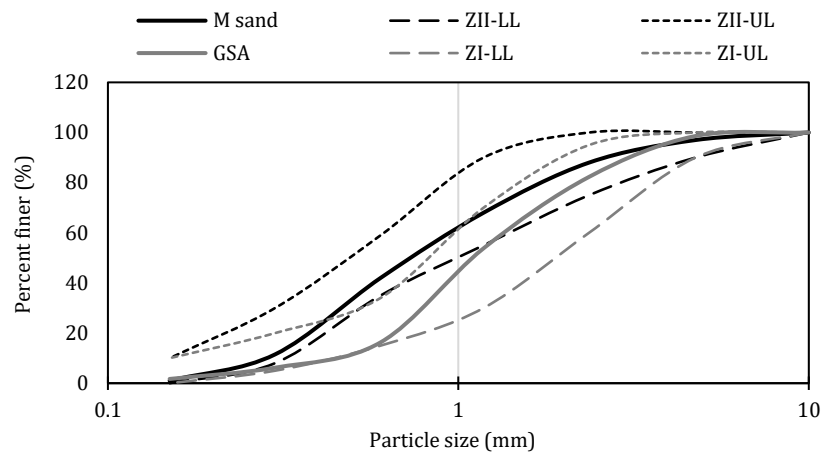


Fig. 2. Grain size distribution of MS and GSA.

Table 3. Mix designation, aggregate composition and mix proportions.

Series	Mix		Aggregate composition (%)				Mix proportions (kg/m ³)						
	No	Id	MS	GSA	NCA	CRA	OPC	GGBS	MK	MS	GSA	NCA	CRA
1	1	MS0	100	–	100	0	278.4	150.3	2.6	945.7	–	753.6	0
	2	MS20	100	–	80	20	275.4	148.7	2.5	935.5	–	596.4	149.1
	3	MS25	100	–	75	25	274.6	148.3	2.5	933.0	–	557.7	185.9
	4	MS30	100	–	70	30	273.9	147.9	2.5	930.5	–	519.1	222.4
	5	MS35	100	–	65	35	273.2	147.5	2.5	928.0	–	480.8	258.8
2	6	GSA0	–	100	100	0	278.6	150.5	2.6	–	946.5	754.2	0.0
	7	GSA20	–	100	80	20	275.6	148.8	2.5	–	936.3	596.9	149.2
	8	GSA 25	–	100	75	25	274.9	148.4	2.5	–	933.7	558.1	186.0
	9	GSA 30	–	100	70	30	274.1	148.1	2.5	–	931.3	519.5	222.6
	10	GSA 35	–	100	65	35	273.4	147.7	2.5	–	928.8	481.2	259.0

Note: Mix Id indicates the type of fine aggregate and CRA content as coarse aggregate.

Ex: Mix Id MS20 indicates SCC made with 100% MS, 20% CRA and 80% NCA.

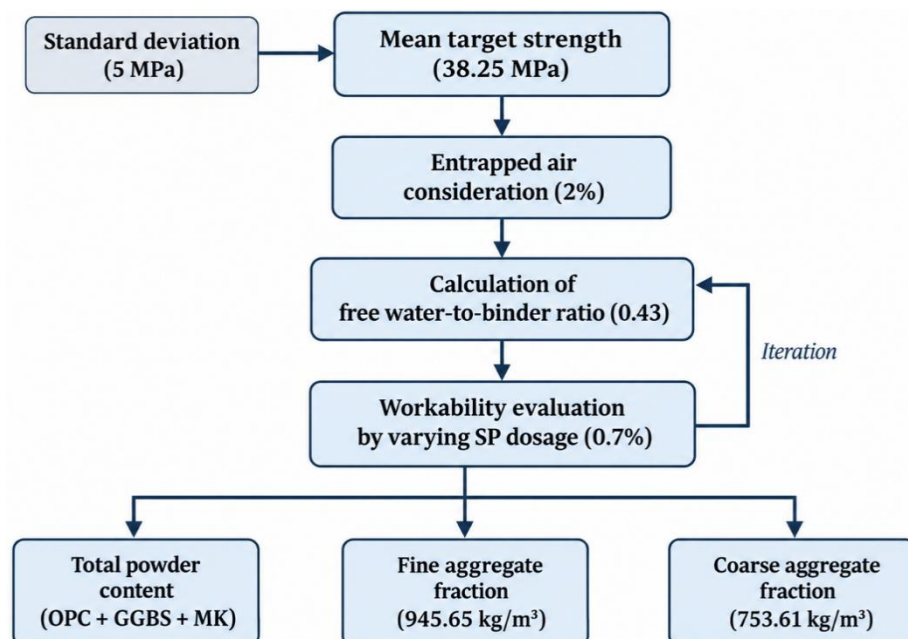


Fig. 3. Flowchart of mix design criteria.

The performance of SCC was investigated by testing cubes of size 150 mm x 150 mm x 150 mm in accordance with various standards (EFNARC 2002; IS 516: Part 1: Sec 1 2021; IS 15658 2021; ASTM C642-13 2013; IS 4456-1 1967). Cubes cast for all mixes were cured in accordance with IS 1199: Part 5 (2018). The cubes were cured for two intervals, 28 and 56 days to investigate the influence of curing duration on characteristics of SCC. Three samples were cast for each property and curing duration.

The acid attack resistance of SCC was evaluated by immersing cubes in 5% sulfuric acid. Three cubes of each mix were immersed in acid solutions for 56 days after 28 days of water curing. The pH of the acid solution was monitored using an electrode-based pH meter with an accuracy of ± 0.01 pH. The acid solution was stored in a shaded room with the temperature variation of 27 ± 1.5 °C. The samples immersed in acid were observed for the development of efflorescence. Degradation of concrete is influenced by acid concentration. The solution was renewed after 30 days to eliminate the neutralization of acid by leaching of alkaline compounds. To ensure consistent degradation, specimens were cleaned to remove deposited salts, loose and disintegrated particles and re-immersed in fresh solution. The water permeability was assessed as per IS 3085 (1965). Permeability was assessed by measuring the depth of water penetration in samples subjected to a hydrostatic pressure of 0.5 MPa for three days.

The degradation resistance of SCC was evaluated by Acid Durability Factor as presented in Eq. (1).

$$\text{Acid Durability Factor (ADF)} = \frac{S_r \times N}{M} \quad (1)$$

where S_r is the relative strength at N days (%), N is the number of days of exposure, and M is the number of days of total test duration.

4. Results and Discussion

4.1. Fresh properties of SCC

The fresh properties of SCC mixes containing CRA and GSA were within the prescribed limits according to EFNARC guidelines. The use of CRA improved the workability of SCC for both series, with MS-based SCC performing marginally better than SCC made with GSA. The limiting slump flow and V-funnel time ranges from 650 to 800 mm and 8 to 12 seconds, respectively for SCC.

M-sand based SCC exhibited marginally higher slump flow values than GSA based SCC with an increase in CRA content. In contrast, with an increase in CRA dosage, M-Sand based SCC attained modestly lower flow time varying from 6 seconds to 10 seconds as compared to GSA based SCC, which varied from 10 to 12 seconds, suggesting slower flow or higher viscosity impeding spread. Figs. 4(a-b) presents the workability based on the slump and V-funnel tests. The variation in workability of MS and GSA mixes containing CRA was less than 2% and 6% for slump and V-funnel test, respectively. The workability of SCC was also ascertained using the L-box and J-ring tests, as shown in Figs. 4(c-d). A stable L-box and J-ring test results were observed for both mixes when the CRA content varied 0 to 25% respectively. However, at higher dosage of CRA, WA characteristics of CRA, resulted in increased L-box and J-Ring test values.

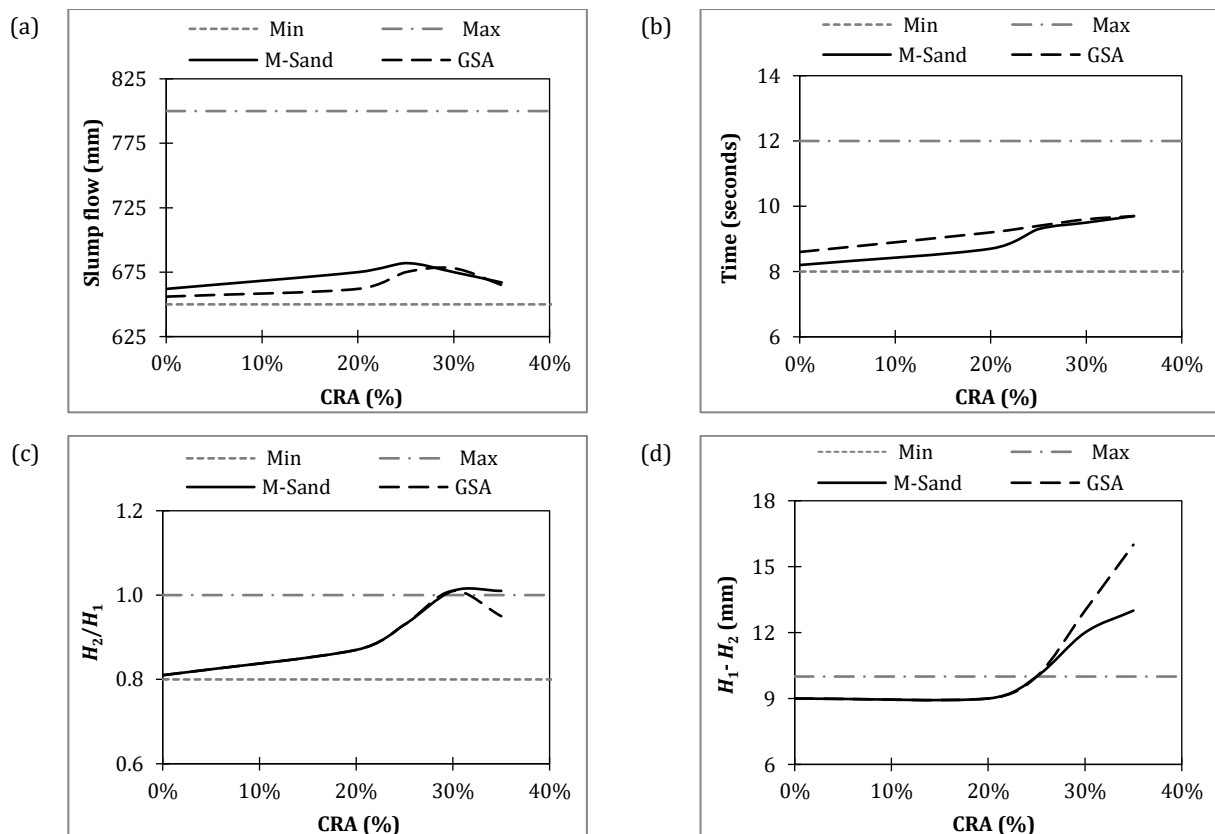


Fig. 4. Workability characteristics of SCC: (a) Slump; (b) V-Funnel; (c) L-box test; (d) J-Ring test.

4.2. Hardened properties of SCC

Cubes samples were tested for compressive strength and water absorption after 28 and 56 days of curing. A total of 120 samples were cast to evaluate various properties. The water permeability and influence of acid attack were evaluated after 28 and 56 days of curing, respectively. Table 4 presents the test results of SCC samples. The Influence of CRA content, curing duration and WA of aggregate on compressive strength and water absorption of SCC is presented in Fig. 5.

The hardened properties of series-2 SCC with NCA substituted by CRA up to 20% were better than those made with MS. Series-2 SCC exhibited 1.90–7.22% higher compressive strength than series-1 SCC. A similar observation was noted by Gupta and Siddique (2020).

Further increment in CRA dosage resulted in 4.5–13.1% reduced compressive strength for GSA based SCC. According to Sasanipour and Aslani (2020), when 25% of NCA was substituted by CRA, compressive strength of SCC decreased by 32%. The loss of compressive strength was less than 10% for series-1 and series-2 SCC with CRA dosages of 25% and 20% for samples tested at 28 and 56 days respectively.

An increase in curing duration resulted in latent strength gain of 7.3% and 3.27% lowered strength loss as compared to 28 days cured samples. Use of GSA resulted in 4.0 to 13.2% improved strength for extended curing duration. This late age strength gain is attributed to presence mineral admixture in binder composition and lower water absorption of GSA. The variation in loss of compressive strength is shown in Figs. 5(a-b).

Table 4. Mechanical and durability properties of SCC.

Series	Mix		σ_c (MPa)				WA (%)		Water permeability (mm)	Mass loss (%)	Acid treatment for 56 days			
	No	Id	28 (day)	CoV (%)	56 (day)	CoV (%)	28 (day)	56 (day)			σ_c (MPa)	CoV (%)	σ_c loss (%)	ADF (%)
1	1	MS0	35.2	1.4	36.3	1.2	1.1	0.5	22.1	1.0	35.1	2.4	3.1	96.9
	2	MS20	34.1	1.5	35.2	1.2	1.6	0.9	22.8	1.3	33.8	2.5	4.0	96.0
	3	MS25	32.8	1.8	34.4	1.3	1.9	1.1	23.6	1.7	32.7	2.8	5.1	94.9
	4	MS30	30.6	2.1	31.7	1.5	2.1	1.5	24.2	1.9	29.7	3.2	6.1	93.9
	5	MS35	27.8	2.6	29.8	1.8	2.3	1.8	24.8	2.4	27.6	4.2	7.5	92.5
2	6	GSA0	35.9	1.4	38.9	1.1	0.2	0.2	21.9	0.4	37.9	1.2	2.6	97.4
	7	GSA20	35.1	1.5	36.5	1.2	0.5	0.4	22.4	0.5	35.2	1.5	3.4	96.6
	8	GSA25	29.1	1.6	32.7	1.2	0.8	0.7	23.2	0.5	31.1	1.6	4.7	95.3
	9	GSA30	27.4	1.8	30.2	1.4	0.9	0.8	23.7	0.5	28.5	1.8	5.6	94.4
	10	GSA35	24.2	2.0	27.4	1.5	1.0	0.9	24.5	0.6	25.5	2.0	6.9	93.1

Note: CoV - coefficient of variation.

Incorporation of CRA also increased the WA of the hardened sample. Maximum WA of the SCC made with MS and GSA was lower than the limiting value of 6% (IS 15658 (2021)). The WA of MS based SCC mixes were 2.3 to 4.8 times higher than that of GSA based SCC. This increased WA of SCC is due to the absorption characteristics of MS, NCA and CRA. WA characteristics of the aggregate fraction were found to vary from 1.07 to 1.34% and 0.69 to 0.96% when the fine aggregate was MS and GSA respectively. This increased WA of aggregate fraction prompted increase in WA of SCC. As the curing duration was doubled from 28 to 56 days, WA of SCC was reduced by 22 to 56% and 11 to 30% for series-1 and series-2 SCC mixes respectively. An increased CRA content (30 and 35%) and curing duration (28 to 56 days) indicated unit increase in WA of SCC. The influence of CRA content and curing duration on WA of SCC mixes is shown in Fig. 5(b). WA of aggregate fraction viz., fine and coarse aggregates was influenced by intrinsic absorption characteristics of aggregates and was found to affect compressive strength and WA of SCC. Increase in

WA of aggregate resulted a decrease in compressive strength and increase in WA of SCC as illustrated in Figs. 5(c-d).

Water penetration depth of NCA based SCC via., permeability test ranged from 21.9 mm (GSA0) to 22.1 mm (MS0). It is interesting to note that GSA based SCC exhibited increased resistance to water penetration compared to series-1 SCC. The coefficient of determination of the percentage of permeability was 0.99. Water penetration increased with increment in CRA content, as presented in Fig. 6(a). This is due to porous nature and water absorption capacity of CRA. Increase in permeability of SCC was noted for every 5% increment in CRA dosage. Maximum water permeability was 24.8 mm, observed for SCC mix MS35. Considering the depth of the sample viz., 150 mm, permeability varied from 14.73 to 16.53% and 14.60 to 16.33% for MS and GSA based SCC respectively as illustrated in Fig. 6(b) with coefficient of determination being of the order 0.98 to 0.99. The coefficients of variation of compressive strength, water absorption and permeability were less than 5%.

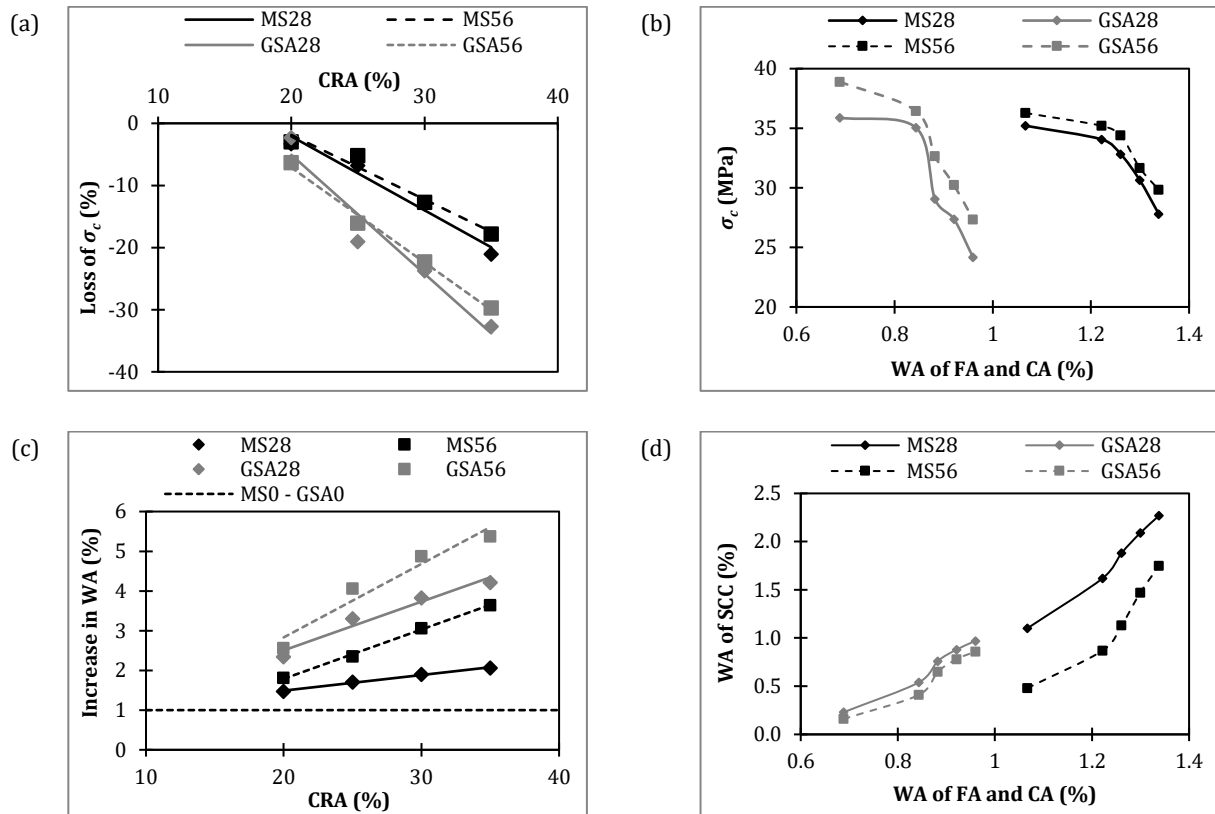


Fig. 5. Influence of CRA content, curing duration and WA of aggregate on: (a) CRA vs Loss of σ_c ; (b) CRA vs water absorption of SCC; (c) WA of aggregate versus σ_c ; (d) WA of aggregate versus WA of SCC.

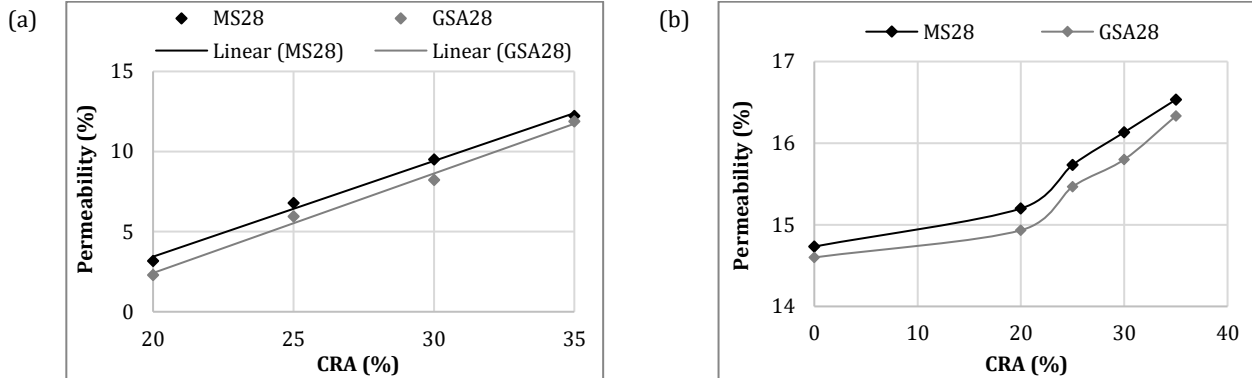


Fig. 6. Influence of CRA on permeability of SCC: (a) Compared with MS0 and GSA0; (b) Compared to depth of cube.

4.3. Effect of acid attack on concrete

SCC samples were immersed in a 5% acidic solution for 56 days. Exposure of SCC cubes to the acid solution did not affect the colour. However, disintegration and scaling were noted in cubes, as shown in Figs. 7(a-b). The cementitious paste around the surface of the specimen was completely disintegrated (pitting of concrete) exposing the central core as indicated in Fig. 7(c). The decomposition of alkaline compounds was predominantly observed in MS-based SCC mixes. The SCC containing GSA exhibited improved resistance to external sulfate attack compared to those made with MS. Samples made with GSA exhibited mild efflorescence at the edges of sample with minimal visual distortion as shown in Fig. 7(d).

The weight loss of GSA based SCC immersed in an acid solution for 56 days was found to vary from 0.41 to 0.56% when CRA was varied from 0 to 35%. However, for MS-based SCC, the loss of mass was 2.41 to 4.27 times higher than that of GSA based mixes at similar CRA contents.

The variation in compressive strength of SCC immersed in an acid solution was also explored. It can be noted from Table 4 that the compressive strength of SCC decreased when exposed to an acidic environment due to decomposition of calcium hydroxide (C) and calcium silicate hydrate (C-S-H). This loss of strength was measured as the difference of compressive strength of samples cured in water and samples immersed in acid, as presented in Eq. (2).

$$\text{Loss of } \sigma_c = \sigma_{c \text{ water cured}} - \sigma_{c \text{ immersed in acid}} \quad (2)$$

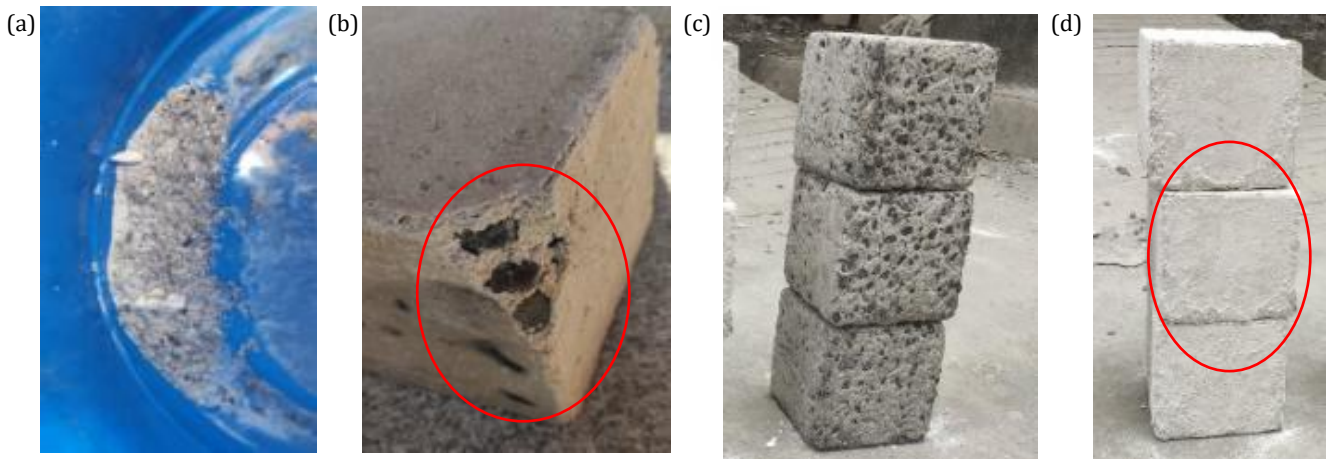


Fig. 7. Effect of acid exposure on SCC:

(a) Disintegrated concrete; (b) Scaling; (c) Pitting - MS56; (d) Efflorescence - GSA56.

It can be noted from Table 4, that series-2 SCC exhibited lower loss of strength than series-1 SCC. As the CRA content varied from 0% to 35%, the loss of strength of series-1 and series-2 SCC varied from 1.1 to 2.2 MPa and 1.0 to 1.9 MPa, respectively.

The effect of acid exposure on the performance properties of SCC is shown in Fig. 8. As compared to water-

cured samples, acid exposed SCC resulted in a progressive reduction in compressive strength from 2.60 to 7.52%. The experimental investigations indicated that series-2 SCC exhibited higher resistance to loss of strength than series-1 SCC as shown in Fig. 8(a). The acid durability factor (ADF) of series-2 SCC outperformed series-1 SCC as shown in Fig. 8(b).

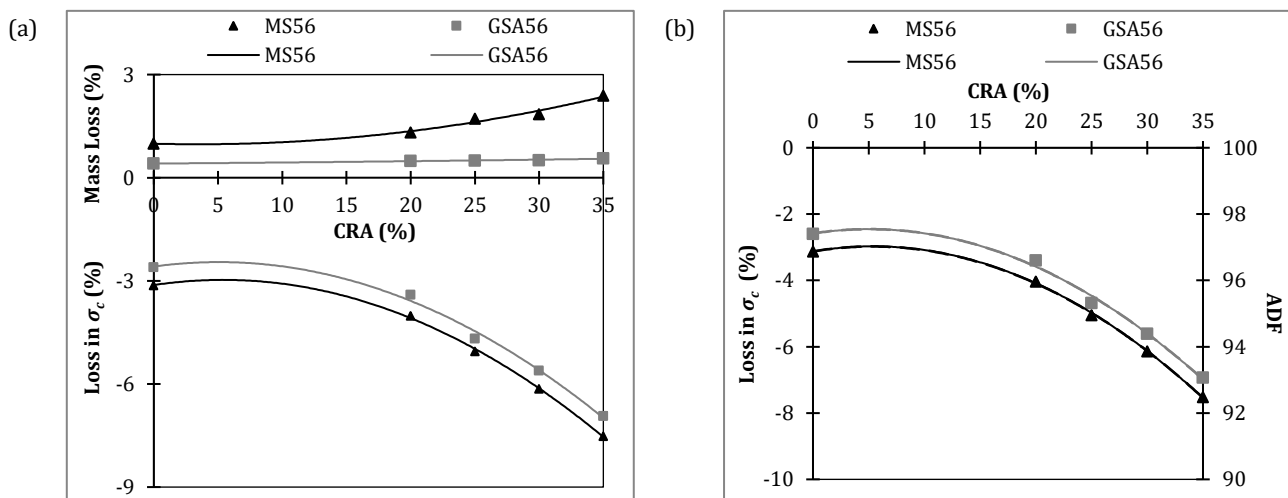


Fig. 8. Performance variation of SCC due to acid exposure:

(a) Effect of acid attack on strength and mass loss; (b) Influence of CRA on strength loss and ADF.

4.4. Microstructure of SCC

In comparison to various SCC mixes explored, utilization of GSA in SCC exhibited improved performance, with 28-day compressive strength of the order of 35 MPa. Topographic analysis of SCC was performed using SEM, for specimens cast with GSA containing 0 and 20% CRA, namely, GSA0 and GSA20 at two magnification levels of 3.00 μm and 10.00 μm as presented in Fig. 9.

The microstructure of samples indicated presence of ettringite (E), void spaces, a clear spread of calcium silicate hydrate (C-S-H) gel and calcium hydroxide (C) as presented in Fig. 9(a).

An increased ettringite formation and low-density sample was observed in SCC with the use of CRA as a partial substitute to NCA as shown in Fig. 9(b). The Interfacial Transition Zone (ITZ) of SCC with NCA indicated dense bonding with aggregate and lower porosity as presented in Fig. 9(c). Utilization of CRA in SCC exhibited increased porosity due to increased voids as shown in Fig. 9(d).

GSA20 SCC was more porous than that of GSA0 SCC which also contributed in an increase in water absorption. This was noticed with increase in permeability and water absorption from 21.9 mm to 22.4 mm and 0.23 to 0.54% respectively, when CRA utilization was varied from 0 to 20%.

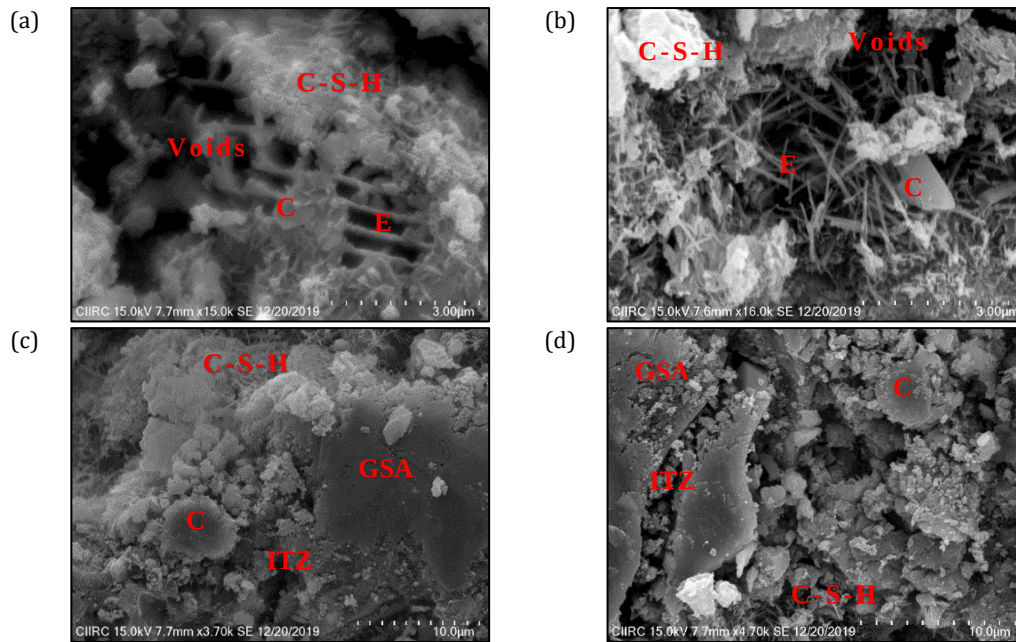


Fig. 9. SEM micrographs: (a) GSA0 at 3 μm ; (b) GSA20 at 3 μm ; (c) GSA0 at 10 μm ; (d) GSA20 at 10 μm .

5. Conclusions

The current study explores the suitability of GSA and CRA in development of SCC. Performance of SCC was investigated for compressive strength, water absorption, permeability and acid attack. A 5% sulfuric acid solution was used to evaluate the resistance of SCC subjected to aggressive environment. The variables governing properties of SCC namely, water to binder ratio and SP dosage were maintained constant at 0.43 and 0.7%, respectively. The Binder paste volume and aggregate to cement ratio was 0.35 and 3.94 respectively. Based on experimental investigations the following conclusions were drawn.

Workability of both SCC series were within the limits prescribed by EFNARC. The variation in workability of MS and GSA mixes containing CRA was found vary from 0% to 6%.

- Use of CRA resulted in reduced performance of SCC. Loss of compressive strength was less than 10% for series-1 and series-2 SCC incorporating CRA contents of 25% and 20%, respectively. Curing duration resulted in an increase in compressive strength by 3.4 to 7.3% and 8.4 to 13.2% for MS and GSA-based SCC, respectively.
- Water absorption of CRA-based SCC made with MS and GSA was less than the limiting value of 6%. Comparable permeability was observed in SCC mixes with 20% CRA. Maximum permeability of 24.8 and 24.5 mm was observed for mixes MS35 and GSA35, respectively.
- Acid attack resulted in decomposition of alkaline compounds with reduction in weight by series-1 and series-2 SCC by 2.39% and 0.56%, respectively. Compressive strength also reduced from 1.1 to 2.2 MPa and 1.0 to 1.9 MPa for MS and GSA based SCC, respectively. The GSA-based SCC exhibited improved performance compared to the MS-based SCC.

The current research indicates that GSA can be used as a substitute for MS in development of SCC, when the

properties of GSA and MS are comparable. The performance of SCC improved with the utilization of GSA as fine aggregate and 20% NCA replaced with CRA, promoting a sustainable approach for SCC production.

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Conflict of Interest

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Author Contributions

All authors made substantial contributions to the conception and design of the study, acquisition of data, analysis and interpretation of data; drafted or critically revised the manuscript for important intellectual content; and approved the final version to be published.

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