Indian Journal of Engineering & Materials Sciences
Vol. 32, August 2025, pp. 438-446
DOI: 10.56042/ijems.v32i04.16937

Enhanced mechanical and durability performance of dry mix concrete made with silica-coated aggregates

Humaira Athar[a*], Raghunandan Kadaba[b], Lok Pratap Singh[a] & Pradeep Rawat[a]
[a]CSIR-Central Building Research Institute, Roorkee 247 667, India
[b]Bawri Group, Kolkata 700001, India

Received: 05 February 2025; accepted: 30 June 2025

This research work has focused on enhancing the mechanical and durability properties of M40 grade concrete by replacing natural granite coarse aggregates with silica-coated granite aggregates. The mix has been further improved by changing the order of mixing ingredients and by using a mechanically modifying binder. Improvement in the fresh state properties of all the mixes has been observed due to the formation of a lubricating layer over the aggregates as a result of the slurry coating, compared to control concrete. Around 48% increase in 28 days' compressive strength, 47% enhancement in flexural strength, and 36% in tensile strength have been observed with the modified formulations. Furthermore, the enhanced formulation has lowered the chloride penetration by 20% and water penetration by 80%. The dense interfacial transition zone of scanning electron microscopic images has shown that the use of silica-coated aggregates, along with mechanically modifying the binder and changing the order of mixing, has imparted superior mechanical and durability properties to the concrete compared to conventional methods.

Keywords: Coarse aggregates, Compressive strength, Interfacial transition zone, Mechanically modified binder, Water absorption

1 Introduction

Concrete plays a key part of modern civilization as it has a remarkable performance as compared to any other building materials and therefore, it is world's most consumable man made material. Despite being a relatively easy-to-manage material, concrete and its reinforcement have been linked to several structural problems in the building industry. The performance of concrete is always a major task for concrete technologist, which mainly depends on its ingredients and its mixing proportions. Mixing sequence of concrete does not have any general rules[1]. The sequence of introduction of constituents into a mixer varies from plant to plant[2]. Concrete is made up of cement, fine and coarse aggregates, mineral and chemical admixtures, water, etc. and mixing of these materials in a defined ratio is known as mix design. Concrete mix design necessitates thorough understanding of the properties of the materials, the implications in case these conditions change at the site, the effects of plastic concrete's properties on hardened concrete, and the complex interrelationships between the variables[3]. The primary goal of the mixing process of concrete is to get a homogenous mix of all the raw materials. When concrete is improperly mixed, it not only affects the fresh properties but also the hardened properties[2]. Traditionally, mixing of large scaled methods are mentioned in ASTM C94[4], and in accordance with this, firstly water is feed into the mixer and then other raw materials (cement, fine, and coarse aggregates and mineral additions if any) is added to the mixer. The remaining water is then mixed with a liquid chemical admixture. As contrary to this, ASTM C192[5] suggests a way of mixing, whereby some amount of water and coarse aggregates are added first, followed by fine aggregates and cement. Mineral admixtures are added after the remaining water has been evenly mixed with liquid admixtures. Contrarily, ASTM C109[6] standard provides the mortar mixing procedure, which entails blending water with cement before adding fine aggregate to create a highly homogenous mixture after adequate mixing time. The procedures of mixing sequence given in DIN and ASTM[6,7] are used by the majority of labs. Firstly, a portion of water and coarse aggregates are added and mixed followed by the addition of fine gravel and cement. After that, the liquid admixture is evenly diluted with water, followed by addition of mineral admixtures and

Corresponding author (E-mail: humaira.cbri@csir.res.in)

remaining cement. Similar methods are used for mixing high performance concrete, but the mixing sequence changes as per the required properties of the concrete produced[8]. Rahal[9] examined the mixing practices used in various countries and came to the conclusion that mixing the binder before adding coarse aggregates can lessen the need for water and cement. Further, he added that, the change in mixing sequence leads to an increase of about 10–20% strength. According to Hentges[10], altering the sequence of materials during the mixing process can improve the properties of both freshly-poured and hardened concrete. Several researchers have manufactured recycled aggregates by using the two-stage mixing approach (TSMA)[11-13]. In TSMA, recycled aggregate is coated with a pozzolanic powder of fly ash, silica fume and blast furnace slag and then mixed with the water. This mixing technique is advantageous for the mechanical properties and better workability than normal concrete because of the higher packing density due to various pozzolanic powders. A triple mixing method was used by Kong *et al.*[14] where firstly the aggregates were wetted with part of water, then pozzolanic materials were added and mixed for 15 seconds followed by addition of cement and mixing of 30 seconds. All the materials were mixed homogenously and finally the remaining water was added to the mix. Padovan[15] examined the effects of pre-wetted aggregates in fresh and hardened properties of concrete. The study revealed that the wet aggregates are responsible for releasing water inside concrete and hence increasing the total water content. The pre-wetting of aggregates helps in minimizing concrete's damaged surface. Researches[11-13] improved the process of mixing of concrete in order to obtain an aggregate surface with less porosity and less fracture. Firstly, a slurry of cement and mineral admixture was made then pre-wetted recycled coarse aggregates were added to it. By this improvement in the mixing process, an enhancement in the concrete's compressive strength and workability was observed which was also verified by a denser old cement mortar. Oyanadel[16] used a two-step mixing process in which firstly a homogenous paste was made with cement and water and then aggregates were added in next stage. In the hardened concrete, an improvement in the interfacial transition zone (ITZ) between the coarse aggregates and cement paste was clearly observed which may be due to the mitigation of the 'wall' effect[1,17]. Erhart *et al.*[18] mixed mineral admixtures followed by the concrete recycled coarse aggregates at the end of the mixing process and found an improvement on both fresh and hardened state properties in the concrete.

Previous researches have shown either the effect of mixing sequence, coating of aggregates or grinding fine aggregates to improve the fresh and hardened properties of concrete. In this context, the present work aims to use a new mixing method which combines the pozzolana-coated coarse aggregates, manufactured sand, and a mechanically modified binder to improve the performance of concrete. The synergistic effects of the modified formulation are investigated on the fresh, hardened, and microstructural properties of the concrete.

2 Materials & Methods

2.1 Raw materials

In this research work, all the raw materials were provided by Bawri Group, Kolkata, India. There were four different concrete supplied in terms of mass of dry mixed concrete separately packed in bags and labelled. The company specified that the binder consisted the combination of cement, mineral and chemical admixtures. Binder comprised of homogeneous mix of OPC 53 grade cement and class F flyash. The mass of cement including mineral additive was presented in unit volume of specified mix. Dry polycarboxylate based super plasticizer was used as the chemical admixture. The cement, mineral and chemical admixtures were in accordance with the requirements of IS 456:2000[19]. Manufactured sand (M-sand) confirming to Zone II as per the requirements of IS 383:2016[20] was used. Specific gravity of M-sand was 2.58 and water absorption was 3.75%. The sieve analysis of the fine aggregate is given in Table 1. Granite angular crushed aggregates of sizes 20 mm down and 12.5 mm down confirming to IS 383:2016, were used as coarse aggregates (Fig 1[a-b]). The

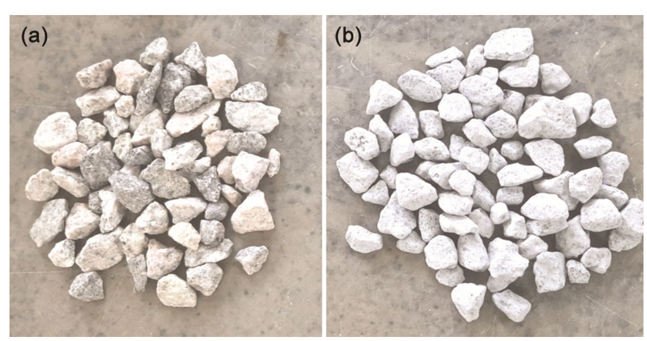

Fig. 1 — (a) Uncoated natural granite aggregates (b) Coated natural granite aggregates.

Table 1 — Characteristics of fine aggregate.

IS Sieve Designation	Cumulative Percentage		Specification as per IS:383-2016 (% passing)		
	Retained (%)	Passing (%)	Zone I	Zone II	Zone III
4.75 mm	0	100	90-100	90-100	90-100
2.36 mm	17.5	82.8	60-95	75-100	85-100
1.18 mm	19.1	63.4	30-70	55-90	75-100
0.6 mm	17	40.4	15-34	35-59	60-79
0.3 mm	15	31.4	5-20	8-30	12-40
0.15 mm	13.3	18.1	0-10	0-10	0-10
Pan	18.1	0			

Table 2 — Characteristics of coarse aggregate of 20mm down size.

IS Sieve Designation	Cumulative Percent		Specification as per IS:383-2016 in respect of 20 mm nominal size aggregate (% passing) Graded	Single sized
	Retained (%)	Passing (%)		
40 mm	0	100	100	100
20 mm	4.6	95.4	95-100	85-100
12 mm	93.7	1.7	--	--
10 mm	1.3	0.4	25-55	0-20
4.75 mm	0.4	0	0-10	0-5

Table 3 — Characteristics of coarse aggregate of 12.5 mm down size.

IS Sieve Designation	Cumulative percent		Specification as per IS:383-2016 in respect of 12.5mm nominal size aggregate (% passing) Graded	Single sized
	Retained (%)	Passing (%)		
20 mm	0	100	100	100
12.5 mm	1.8	98.2	90-100	85-100
10 mm	25.7	72.5	40-85	0-45
4.75 mm	68.7	3.8	0-10	0-10
2.36 mm	3.8	0		

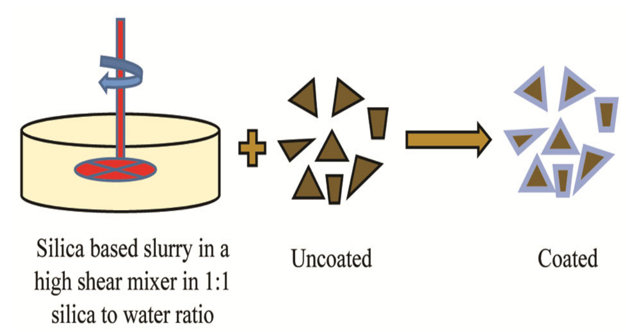

Fig. 2 — Pictorial representation of process of coating of coarse aggregates.

specific gravity of 20 mm and 12.5 mm size aggregates were 2.69 and 2.68 respectively while water absorption was 0.3% and 0.55 % respectively. The sieve analysis of the 10 mm and 20 mm down coarse aggregates is given in Table 2 and Table 3. Silica based slurry was mixed with water in a 1:1 ratio and mixed in a high shear mixer for about 1 minute. Uncoated coarse aggregates were coated with this slurry and dried. Pictorial representation of coating of coarse aggregates is shown in Fig. 2 and SEM image of silica coated granite coarse aggregate is shown in Fig. 3. Potable water conforming to the requirements of IS 456 was used during the entire concreting operations.

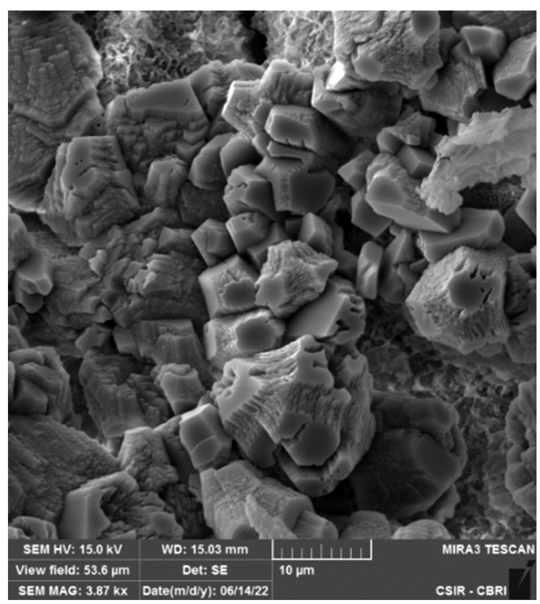

Fig. 3 — FE-SEM image of coated coarse aggregates.

2.2 Mix proportion

The mix proportioning of different mixes is given in Table 4 and a pictorial representation of different mixing sequences is shown in Fig. 4. The cement and fly ash content was fixed at 320 kg m^{-3} and 80 kg m^{-3} respectively for all the mixes. The superplasticizer was added in a fixed dosage of 0.8 % by weight of binder in all the mixes. The water to

Table 4 — Quantities of materials for different mixes.

MIX 1		MIX 2	MIX 3		MIX 4
Control concrete- Normal concrete with normal sequence of mixing		Normal concrete with normal binders and different sequence of mixing	Engineered binder + different sequence of mixing		Engineered binder + different sequence + coated coarse aggregates
Material	Kgm^{-3}	Kg m^{-3}	Material	Kg m^{-3}	Kg m^{-3}
Cement	320	320	Cement (30% ground+ 70% unground)	320	320
Fly ash	80	80	Fly ash (30% ground +70% unground)	80	80
Fine agg	780	780	Fine agg	780	780
CA 20 mm down	648	648	CA 20	648	648
CA 12.5 mm down	432	432	CA 12.5	432	432
Admixture	3.2	3.2	Admixture	3.2	3.2
w/b ratio	0.39	0.39	w/b	0.39	0.39
Free Water	156	156	Total Water	156	156
Total wt. of batch	2419.2	2419.2	Total wt. of batch	2419.2	2419.2

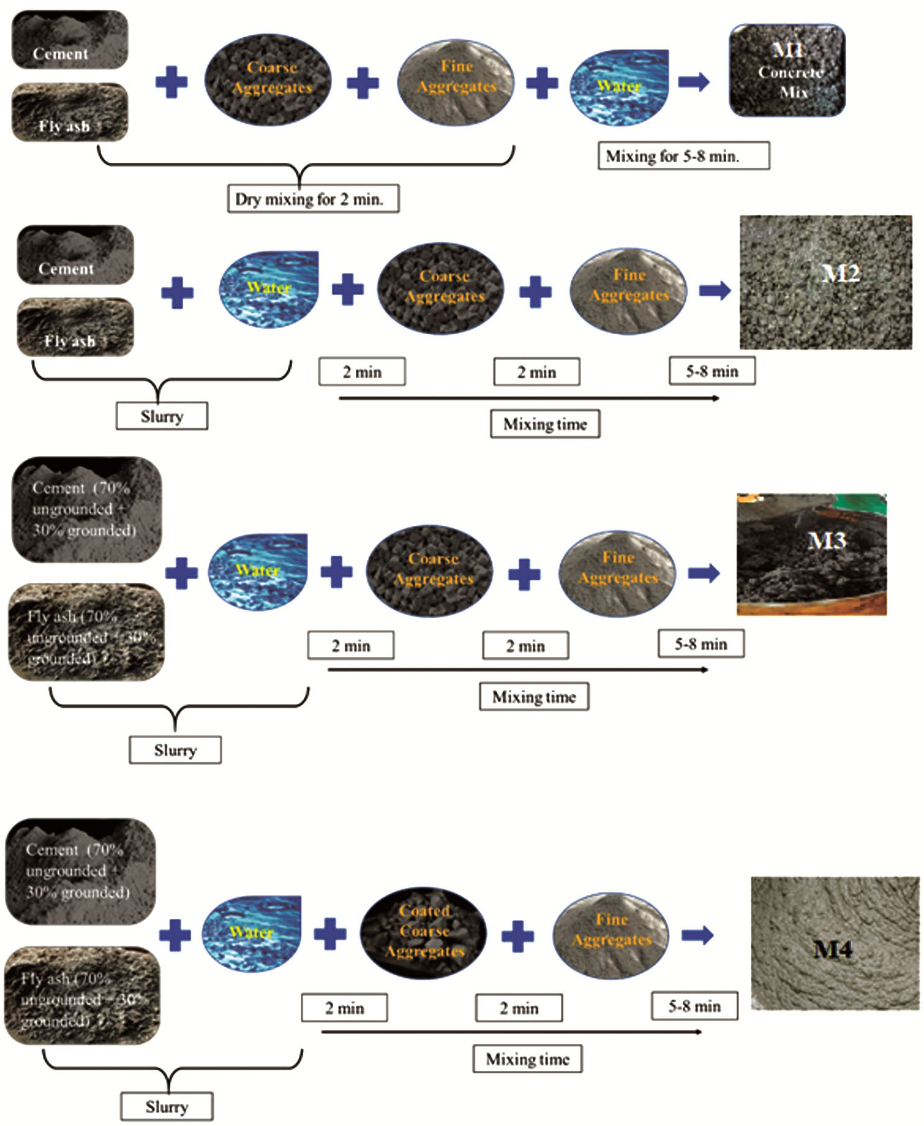

Fig. 4 — Pictorial representation of preparation of different concrete mixes M1, M2, M3 and M4.

binder ratio was kept at 0.39 for all the mixes. The concrete mixes are manufactured using a pan mixer of 60 liters' capacity with a rotating drum and fixed blade. The grade of all the cast concrete was M40. The resulting mix is filled in three equal layers. In the case of cubical molds, each layer was compacted by applying 35 strokes and 25 strokes for 150 x 150 mm cubes and 100 x 100 mm cubes respectively using a standard tamping bar. For cylinders, 30 strokes were applied for each layer. The completely filled molds were subjected to vibration on the vibrating table for about 1-3 minutes. Samples were cured in water for 28 days after demolding and stored in a curing tank maintaining temperature conditions as per IS:456-2000.

2.3 Description of mixes

The mixes were denoted as M1, M2, M3 and M4. Each mixes were different from each other either in mixing sequence or fineness of binder or use of coated aggregates. Different mixes are discussed below in detail:

Mix M1: This was the control mix made for comparison purpose. This was a normal concrete mix consisting of cement, fly ash and aggregates. The casting of mix M1 was carried out with a normal sequence of mixing i.e. first all the dry materials were mixed in a pan mixer for 2-3 minutes followed by adding water and then making a homogeneous mix of all the ingredients.

Mix M2: This mix composition was just like mix M1, the only difference was in the sequence of mixing. Here first the total binder (cement and fly ash) and super plasticizer (in dry form) were added with total water and a thin slurry was made. The bone dry coarse aggregates were added to the slurry and mixed for 2 minutes. After this, fine aggregates were added to the mix and the whole mixture was mixed for 5-8 minutes.

Mix M3: In this mix, the binder was modified and named as engineered binder. The binder consisted of 70% ungrounded cement and 30% grounded cement, 70% ungrounded fly ash and 30% grounded fly ash. The mixing sequence was the same as mix M2, where firstly a thin slurry was made using binder and admixture rotated for about 2 minutes followed by mixing of coarse aggregates rotating for about 2 minutes and then fine aggregates with finally rotating for 5-8 minutes.

Mix M4: Here engineered binder (same as M3) was used with a different sequence of mixing along with coated coarse aggregates. The coarse aggregates were pre-coated with a siliceous coating and dried. The mixing sequence was the same as mix M2 or M3.

2.4 Tests

2.4.1 Fresh properties

The slump test, air content and fresh concrete density of the concrete mixes was as per IS:1199-1959[21]. Cone slump test of different concrete mixes was carried out. The mold was placed on a leveled metal plate. The concrete mix was then filled in three layers, each approximately one-third of the mold and tamped with twenty-five strokes with a tamping rod. The mold was then lifted vertically, immediately after filling the mold. This allows the concrete mix to subside, and the slump is measured. The air content in the freshly mixed concrete is evaluated by the pressure method. The mixes were kept in a air content cylinder, filled in three times equally in layers, each layer is then tampered by rod and following the procedures mentioned in the standard. The pressure was applied in the air content apparatus till pressure reached to 0.02 kg cm^{-2} using small hand pump attached to it. Now, tap on sides wall of the apparatus and then gradually release the pressure through the valve and note the water level from the glass tube. Fresh density of different concrete mixes was calculated during the Air content test. When the mold of the air content apparatus was filled with concrete, it was weighed on the weighing balance. The weight of concrete with apparatus, empty weight of apparatus was noted. Fresh concrete density was calculated by dividing the difference in weight with the volume of apparatus.

2.4.2 Mechanical properties

Concrete cubes are tested for their compressive strength on a 1000 kN capacity compression testing machine. The load was applied steadily and uniformly over the samples, at a rate of 0.25 mm min^{-1} as per IS:516-2021[22]. Three cubes were tested to represent the compressive strength of that particular batch. Specimens have been placed sideways to the side of cube cast, in the CTM. The test has been carried out at the ages of 1, 3, 7, and 28 days. In accordance with rupture of the concrete specimens (100 x 100 x 500 mm) was tested on a Universal testing machine of 400 kN capacity in accordance with IS:516-1959. The two steel rods of 38 mm in diameter were placed under the column specimen, 400 mm apart from each other from the center of the specimen. The load was applied through two rollers mounted at the top, spaced 133.3 mm from the center. The Modulus of rupture is calculated according to the formula given in IS:516-1959. Splitting tensile strength test is the indirect measurement of the tensile strength of concrete by the application of compressive load. Cylindrical specimens of sizes 150 mm diameter and 300 mm height were tested on a compression testing machine (2000 kN capacity) according to IS:5816-1999[23] to measure the splitting tensile strength of concrete. The specimens were placed horizontally between the platens of the CTM along with two packing strips of 15 mm width and 4 mm thickness. All the cylinders have been subjected to the action of compressive force along two opposite edges.

2.4.3 Durability properties

Rapid chloride ion penetration test (Proove'it, Germann Instruments) was carried out according to ASTM C 1202[24]. The cores of size ~95 mm dia by ~50 mm thickness were cast. The test was run at standard 60V DC for 6 hrs. The total charge passed in the samples was recorded. The water permeability test of the concrete specimens was carried out according to DIN 1048-Part 5[7] at a constant water pressure of 5 bars for 72 hrs. At the end of the test, the 150 x 150 x 150 mm cube sample was split into two halves and the depth of the water penetration inside the samples was measured. The abrasion resistance test on the concrete samples was carried out on Cantabro abrasion resistance machine, using ASTM C1747-2015[25]. Using the Los Angeles apparatus, % loss of the samples from constant rubbing and skidding is recorded. All the specimens were cured in water for 28 days (temperature: 27 ºC, relative humidity 65%) before testing.

2.4.4 Microstructure study

A scanning electron microscope (MIRA3 TESCAN) was used to study the morphology of fractured surface of concrete. Before testing, the specimen was coated with the $AuPd^{-1}$ to render them conductive. The morphology of various concrete mixes was analyzed at different locations. The SEM examination was focused on ITZ of all the samples for comparison purpose.

3 Results & Discussion

3.1 Fresh properties

Slump test, air content and fresh concrete density were evaluated for different mixes. It was observed that the workability of mix M3 was significantly better than control mix M1, and an increase of 100% in slump was obtained. Mix M2 and M4 had no changes in the slump value. The air content values of mixes M1, M2, M3 and M4 are 3.1%, 2.2%, 2.2% and 2.3% respectively are under the permissible limit mentioned for cement concrete as per IS:456-2000. The change in mixing sequence shows equal or superior results in air content reduction as compared to the control mix, as reported by Marija[26]. Marginal change in fresh concrete densities was observed for all the concrete mixes. The densities of fresh concrete of mixes M1, M2, M3 and M4 are 2399 kg m^{-3}, 2409 kg m^{-3}, 2389 kg m^{-3} and 2412 kg m^{-3} respectively. The fresh concrete properties of different mixes of concrete are tabulated in Table 5. The improvement in workability in this study can be attributable to the thin coating film made from silica based product on the coarse aggregates, which slowed down the water absorption behavior of coarse aggregates. The binder slurry acted as a lubricant for the aggregates and hence synergistically both lead to the enhancement of workability. Similar results were shown by Li *et al*.[27], where the pozzolanic materials forms a barrier to the inner bleeding of water when applied as coating layer on the aggregates resulting in the strengthening of ITZ and improvement of workability. Hiremath *et al*.[28] found that addition of water and superplasticizer with binding materials initially enhance the flow and strength result.

3.2 Mechanical properties

The 1-day compressive strength of concrete mixes M2, M3 and M4 was 21.4%, 50.8% and 48.5% more than M1 i.e., the control specimen respectively. The 3-day compressive strength of concrete mixes M2, M3 and M4 was 17.2%, 33% and 22.7% more than M1 i.e., the control specimen respectively. The 7-day compressive strength of concrete mixes M2, M3 and M4 was 5.9%, 4.9% and 19.3%, more than M1 i.e., the control specimen respectively. The 28-day compressive strength of concrete mixes M2, M3 and M4 was 3%, 12.8% and 21.2% more than the control specimen M1 respectively (Fig. 5). The flexural strength at 28 days of the M2, M3 and M4 was

Table 5 — Fresh Concrete Properties of different mixes of concrete.

Sample	Slump (mm)	Air content (%)	Fresh concrete density (Kg m^{-3})
M1	50	3.1	2399
M2	30	2.2	2409
M3	100	2.2	2389
M4	50	2.3	2412

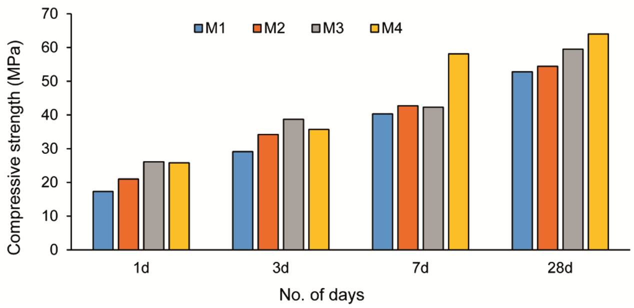

Fig.5 — Compressive strength results of different concrete mixes at different time period.

3.5%, 36.8% and 47% more than the control specimen M1 respectively. The splitting tensile strength at 28 days of the concrete mixes M2, M3 and M4 was 3.3%, 6.7% and 36.7% more than the control specimen M1 respectively.

3.3 Durability properties

The water permeability of different concrete mixes under hydrostatic conditions were evaluated. After 72 hours the depth of penetration of water was found to be 10 mm for control sample M1, 5 mm for M2, 5 mm for M3 and 2 mm for M4, which was 50%, 50% and 80% lesser than the control mix respectively.

The rapid chloride penetration test values of control Mix M2, M3 and M4 are 6.2%, 8.8% and 20.5% lesser than the control sample M1. The control sample falls in the 'low rapid chloride permeability' class while mixes M2, M3 and M4fall in the 'very low rapid chloride permeability' class as per ASTM C 1202-07.

Abrasion resistance of concrete: The test on concrete samples were conducted after 28 days of water curing. The average percentage loss in weights of concrete cylinders M2, M3 and M4 mixes were 0%, 6% and 11% lesser respectively w.r.t control specimen M1. Figure 6 shows the specimens subjected to abrasion test.

3.4 Microstructure study

The microstructure of ITZ is shown in Fig 7 (a-d). Mix 1 and Mix 2 have the same proportion, but due to different mixing sequences, the ITZ is different in these two mixes. Mix 2 shows denser ITZ with an average width of 2.47 µm while the width of ITZ of M1 is 16.62 µm. This result is similar as made by Bentz[29].

Figure 8 shows the plot between splitting tensile strength, compressive strength, and flexural strength. It is evident that the mechanical properties of concrete significantly enhanced when mixing sequence was

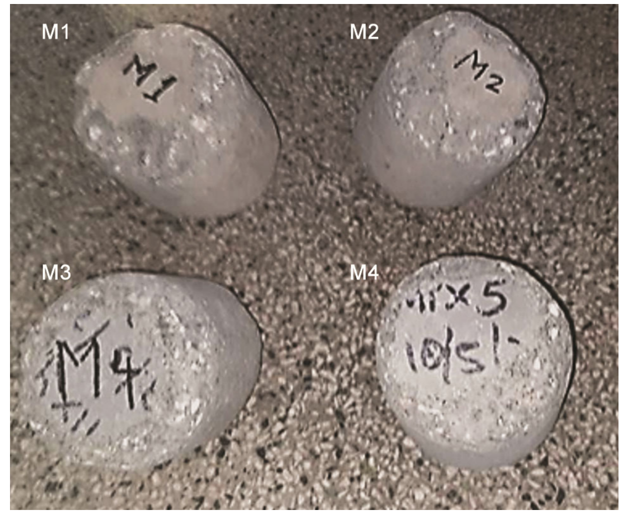

Fig. 6 — Abraded surface of different concrete mixes after Cantabro abrasion test.

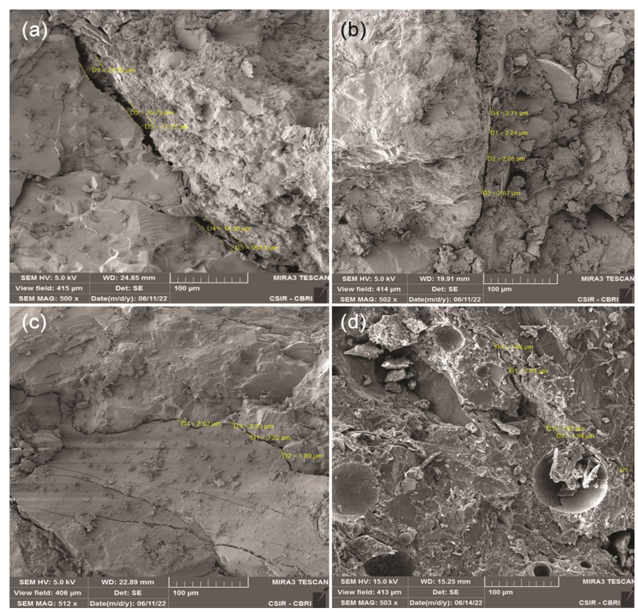

Fig. 7 — FE-SEM images of hardened different concrete mixes (a) M1 (b) M2 (c) M3 and (d) M4.

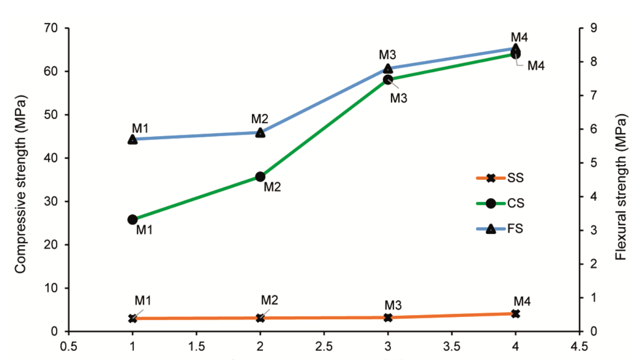

Fig. 8 — Plot between compressive strength, flexural strength and splitting tensile strength of various concrete mixes.

altered, coated aggregates were used, and binder was mechanically modified. The enhancement in the hardened properties of different concrete mixes w.r.t control may be due to the weak Van der Walls forces between calcium silicate hydrates and calcium hydroxide. The cement slurry forms a thin coating over coarse aggregates which results in the formation of hydration products (calcium silicate hydrate) in the Interfacial Transition Zone. The newly modified concrete exhibited denser microstructure due to CSH and additional CSH formation. In the case of the control specimen, where the first mixing of all the dry products was carried out, which might have resulted in the adherence of fine sand particles onto the surface of coarse aggregate particles inhibiting the formation of hydration products. The ITZ region has higher size and concentration of crystalline compounds such as calcium hydroxide and ettringite. This leads to a lowering of strength of the ITZ region of the control specimen. The coating of pozzolanic materials on coarse aggregates showed great advantages for improving the mechanical properties as these materials, for enhancing the strength which is due the high packing density. The micro-cracks seem to be filled by the newly formed reaction products which prevent crack propagation. Improved mixing technique resulted in better strength properties. This is in agreement with results presented by Li[27] and Hiremath[28].

Fig. 9 shows the inter-property relationship between air content, RCPT values and compressive strength. As air content decreases, porosity of concrete decreases which results in the decrease of chloride ion penetration and increase of compressive strength. Sample M4 showed considerable increase in water tightness and resistance to chloride ions penetration test. This may be attributed to the sealing effect due to modified calcium silicate hydrates, pore blocking precipitates formation, better packing of ground cement and ground fly ash of mechanically modified binder and the additional hydration products formed due to coated coarse aggregates.

The abrasion resistance of concrete increases with an increase in compactness of mix which is due to the presence of grounded cement and grounded fly ash in mix M3 and M4 (Fig. 10). Additional hydration product is formed due to the coated aggregates which produces a denser structure and high packing density. This has also led to the decrease of water ingress through the pores.

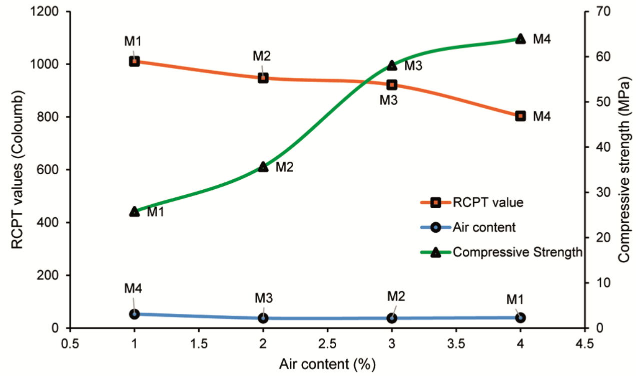

Fig. 9 — Plot between RCPT values, air content and compressive strength of various concrete mixes.

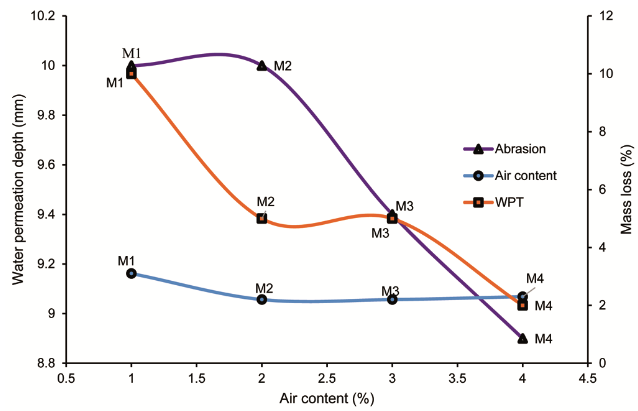

Fig. 10 — Plot between water permeation depth, air content and mass loss of various concrete mixes.

Coating of aggregates with silica does contribute to better strength and dense ITZ. The thickness reduced to 1.67 µm. Possible explanations of dense ITZ may be due to the small sizes of mechanically modified binder which lead to better particle packing density and coating of coarse aggregates gave additional hydration products which helped in strengthening the void spaces of ITZ.

4 Conclusion

(1) A new mixing technique for production of dry mix concrete was put forward in this study. The method included changes in mixing sequence of ingredients of concrete, coating of coarse aggregates and mechanical modification of binder content.

(2) Mechanically modified binder leads to the increment of mechanical strength (compression, flexure and splitting tensile strength) of engineered concrete. It gave a well compacted dense structure to the concrete. Changing the

sequence of mixing leads to the formation of layer of binder slurry on the surface of coarse aggregates thus providing a more reactive site for the formation of hydration products.

(3) Among various mixes, M4 produced effective results in hardened properties which is primarily attributable to the synergistic effect of modifying the binder, coating the coarse aggregates, and changing the mixing sequence.

(4) FESEM of ITZ confirms that coarse aggregates coated with siliceous materials enhance the workability and strength performance due to dense ITZ structure.

Acknowledgement

The author is grateful to the CSIR-CBRI for granting permission to publish this work. The financial support provided by Bawri Group Company, Kolkata for supporting sponsored project No. SSP-0112 is also gratefully acknowledged.

References

1 Mehta P K & Monteiro P J, Concrete microstructure, properties, and materials (McGraw-Hill, California); 3rdEdn, (2006).
2 American Concrete Institute, Guide for Measuring, Mixing, Transporting, and Placing Concrete, ACI 304R-00, Farmington Hills, Michigan(2000).
3 Shetty M S & Jain A K, Concrete Technology: Theory & Practice, (S. Chand & Company Ltd. New Delhi), 5thEdn (2019).
4 ASTM International, *Specification for Ready-Mixed Concrete*, ASTM C94-95, West Conshohocken, Pennsylvania (1995).
5 ASTM International, *Practice for Making and Curing Concrete Test Specimens in the Laboratory,* ASTM C31-95. West Conshohocken, Pennsylvania (1995).
6 ASTM International, *Test for Compressive Strength of Cement Mortars*. ASTM C109-95, West Conshohocken, Pennsylvania (1995).
7 DIN 1048-5, *Testing of Concrete: Testing of Hardened Concrete (Specimens Prepared in Moulds)*, Germany (1991).
8 Chang P K & Peng Y N, *Cement and Conc Res*, 31(2001) 87.
9 Rahal K, *Bldg& Environ*, 42(2007) 407.
10 Hentges TI, Kautzmann VO, Kulakowski MP, Nogueira JR, Kazmierczak C D & Mancio M, *Eur J Environ Civil Eng*, 26 (2022) 1807.
11 Tam VW, Gao X F & Tam C M, *Cem & Concr Res*. 35 (2005) 1195.
12 Tam VW, Gao X F & Tam C M, *Human & Ecological Risk Assess: An Intl J*, 12 (2006) 277.
13 Roesler JR, Lange D, Salas A, Brand A S & Arboleda C, *Center for Excellence in Airport Technology*, Urbana, IL, USA, COE Report, 34 (2013).
14 Kong D, Lei T, Zheng J, Ma C, Jiang J & Jiang J, *Constr & Bldg Mat*, 24 (2010) 701.
15 Padovan R G, Influence of pre-wetting on the properties of concrete produced with recycled concrete aggregate, PhD Thesis, Universidade do Vale do Rio dos Sinos (UNISINOS), São Leopoldo, Brasil. 2013.
16 Latorre Oyanadel, V.V., 2009. Influencia del contenido de adiciones puzolánicas y del proceso de elaboración de la mezclaen la Resistencia mecánica del hormigón.
17 Scrivener KL, Crumbie AK, Laugesen P, *Intrface Sci,* 12 (2004) 411.
18 Erhart R, Schäfer M, Souza R, Kras B J, Mancio M & Kulakowski M, Influence of rice husk ash on the strength and water absorption of concrete produced with recycled coarse aggregates, Proc of the 56th Brazilian Concrete Congress (CONBRAC) (2014) 56.
19 Bureau of Indian Standards, *Plain and Reinforced Concrete – Code of Practice,* IS 456:2000, New Delhi (2021).
20 Bureau of Indian Standards, Coarse and Fine Aggregate for Concrete – Specification. IS 383:2016, New Delhi (2016).
21 Bureau of Indian Standards, Indian Standard Methods of Sampling and Analysis of Concrete. IS 1199:1959, New Delhi (1959).
22 Bureau of Indian Standards, Methods of Test for Strength of Concrete, IS 516:1959, New Delhi (1959).
23 Bureau of Indian Standards, Splitting Tensile Strength of Concrete – Method of Test. IS 5816:1999. New Delhi (1999).
24 ASTM International, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, ASTM C1202-12, West Conshohocken, Pennsylvania (2012).
25 ASTM International, Standard Test Method for Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion, ASTM C1315-13. West Conshohocken, Pensylvania (2013).
26 Nedeljković M, Mylonas A, Wiktor V, Schlangen E & Visser J, *Constr & Bldg Mat,* 315 (2022) 125750.
27 Li J, Xiao H & Zhou Y, *Constr & Bldg Mat,* 23(2009) 1287.
28 Hiremath P N & Yaragal S C, *Constr & Bldg Mat,* 15 (2017) 271.
29 Bentz DP, *Cem & Concr Res*, 30 (2000) 1121.