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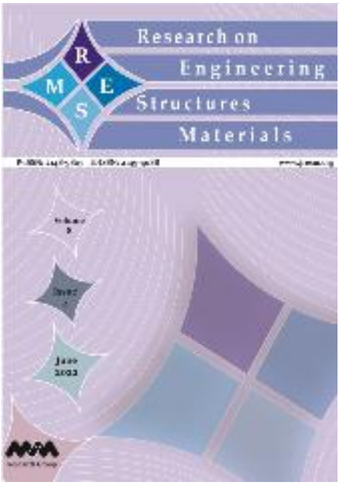

Comprehensive analysis of specimen's properties and fiber type on the performance of Indian origin fine aggregates-based composite

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Research Article

Comprehensive analysis of specimen's properties and fiber type on the performance of Indian origin fine aggregates-based composite

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Abstract

A versatile concept in the field of Engineered Cementitious Composite (ECC) is Eco-friendly ECC. The materials and properties of specimens will influence the characteristics. In this present study, locally available fine aggregates (50% River sand + 50% M-Sand (16.3316^0 N, 80.3514^0 E)) and 2% PVA fibers-based Mix-1, local sand and sisal fibers based Mix-2 (1% sisal fibers + 1% PVA fibers) are considered. The flowability is slightly reduced from Mix-1 to Mix-2. All considered mixes showed good self-consolidation properties (Deformability factor (D.F.) <2.75 based on Li, 2008). For analysis of the mechanical characteristics, different specimens are considered. The compressive and flexural properties negligibly reduced by the size of specimens. But compressive strength moderately reduced by shape (cube to cylindrical specimens). The compressive ratio is between 1.45 to 1.6. The split tensile properties are moderately reduced with the size specimens. All these mechanical characteristics are slightly reduced by the usage of sisal fibres. To determine the durability properties, Rapid chloride penetration (RCPT) test conducted. However, these properties also negligibly influenced by the sisal fibres. It indicates that the sisal fibres can be used for the partial replacement of PVA fibres in the local sand-based mixes. To analyse this, SEM and XRD analysis conducted. Their performance also validated based on Roychand et al, 2016. The hydration of particles and arrangement of fibres are responsible for the significant performance of this Eco-friendly ECC.

1. Introduction

Engineered Cementitious Composite (ECC) is one of the enormous building composites. This is utilizing worldwide as an alternative to conventional concrete due to its tremendous performance [1, 2]. The characteristics of the composites, such as high strength, self-consolidation, crack resistance, etc., are mainly dependent on the properties of the materials [3, 4]. A high dosage of cement in the preparation increases the strength. But it may cause early-age cracks. So a suitable combination of cement with pozzolanic materials is required in the preparation of ECC [5, 6].

Past researchers have studied fly ash's influence on the cement dosage (F/C) and fine aggregates on the composite's performance. Li, 2008. [7] analyzed the influence of silica sand with an F/C ratio on the composite characteristics. The silica sand of 200μm grain size and F/C of 1.2 improved the self-consolidation, mechanical, and durability characteristics. But the economic conditions of silica sand are necessitating alternatives.

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Sherir et al., 2018. [8] analysed the impact of mortar sand on the properties. The composite' flowability and durability were reduced with the usage of mortar sand, but it showed a negligible impact on the mechanical characteristics. The increased content of fly ash has negatively impacted the properties of the composite. It indicates that the properties of fine aggregates and F/C are considerable in the preparation. Apart from this, other materials also will influence the characteristics of the composite.

The crack propagation in this composite can arrest by using fibers, especially Polyvinyl alcohol (PVA) fibers. These bridge the cracks under heavy loads or seismic forces, but fibers' performance depends on the chemical ingredients and oiling agents. Li et al, 2002. [9] studied the impact of the proprietary oiling agents at different concentrations on the PVA fibers' performance. ECC's mechanical characteristics were optimized at 1.2% (weight ratio of oil to fiber) of oiling agents. At this, the debonding energy was also reduced. Fahad et al., 2019. [10] studied the influence of chemical ingredients such as alkyl ketone dimer (AKD), the copolymer of polyurethane, and acrylic epoxy-modified polysiloxane, etc. with oiling agents on the performance of fibers. The flexural characteristics were improved and the composite' debonding energy was reduced with these chemical ingredients with the oiling agents. Pakravan et al, 2015. [11] studied the influence of fibers' properties. For this, PVA fibers and Polypropylene (PE) fibers were considered. The Kidney shaped PVA fibers improved ductility with the combination of polypropylene fibers. Choi et al, 2012. [12] studied the influence of hybridization on performance. The PVA fibers were replaced with Polyethylene terephthalate (P.E.) at different proportions. This combination of fibres has improved performance and reduced construction costs. The usage of PVA fibres are responsible for the environmental problems. To reduce these problems, the usage of natural fibres is necessary. While analysing the test results, the properties of specimens also need to consider due to it may influence the properties. It is helpful to choose the type (shape and size) of elements (The strength may vary by properties) for construction purpose.

In this research work, the impact of specimens' properties and fibres such as sisal fibres and PVA fibres on the Manufactured sand-based mixes have been analysed. The experiments are planned based on future studies on structural components like Paver blocks, bricks, and slabs, etc. Specimens' properties and fibre types are essential factors in these elements. Very limited research done on natural fibres usage in this composite. To analyse its impact, especially sisal fibres at different properties of specimens is necessary for the comprehensive development of elements. It is responsible for the sustainable growth of developing countries like India, Bangladesh, Srilanka, Nepal, etc. In future, these elements can be supplied from Andhra Pradesh (16.3316^0 N, 80.3514^0 E) with affordable prices to different parts of India and other adjacent countries.

2. Experimental Program

In this present study, Fig. 1 (methodology) is considered to analyse the impact of the various factors (influence materials and properties of specimens) on the characteristics. The standard and supplementary materials were considered based on environmental and performance factors. For this, PVA fibres were replaced partially with Sisal fibres and locally available fine aggregates were used in place of Silica sand. The different size and shapes of specimens were considered to analyse the mechanical characteristics. Flowability and durability properties of the composite also determined. The microstructural analysis was conducted to analyse the influence of materials on these properties. Keeping all these into consideration, this research work was planned and executed to obtain Eco-friendly ECC. This methodology was step by step given below.

2.1. Materials

In this study, OPC-53 grade cement is used as per IS 12269-1987 [13]. Class-F fly ash was used to eliminate early-age cracks, according to ASTM 2012a [14]. Locally available River sand (RS) and M-Sand (MS) are used as an alternative to silica sand, as mentioned in Table 2 as per IS 383-2016 [15]. The chemical composition of materials in preparation was mentioned in the Table 1. PVA fibres of 12mm in length and 39µm were used with 0.2% oiling agents to reduce debonding energy. Sisal fibres are used as supplementary material for PVA fibres. These fibres are compatible with the length of PVA fibres. Turbopol CEA50 superplasticizer was used according to ASTM C494 [16]. Taping water in laboratory used. The fibers such as PVA and sisal fibers used in this investigation was shown in the following Fig.4. and Fig.5.

Table 1. Chemical composition

Chemical composition (%)	Cement	Fly ash	RS	MS
Cao	64.35	2.78	0.61	3.45
Sio_2	20.23	59.07	88.75	70.13
Al_2o_3	4.67	25.63	2.92	15.75
Fe_2o_3	3.98	4.57	3.27	2.63
Tio_2	2.56	0.83	0.46	0.25
Mgo	0.45	1.22	0.21	3.67
others	3.76	5.9	4.51	4.15

Table 2. Sieve analysis of local materials

IS sieve size (mm)	Weight retained		Remarks
	RS	MS	
10	0	0	Indian Zone-II category
4.75	17	16	
2.36	176	203	
1.18	181	175	
0.6	256	253	
0.3	189	176	
0.15	152	147	

Fig. 2, and Fig. 4 illustrate the unoiled PVA fibers and Oiled fibers, respectively. The oiling agents applied about 0.2% on the surface of PVA fibers to reduce debonding energy. Initially, these fibers are taken from the local supplied company with a length of 12mm. These fibers are responsible for environmental problems such as toxicity, and disposal problems. To avoid this, sisal fibers are considered in this study. As mentioned in Fig.5, Sisal fibers can collect from the sisal plant (Fig. 3). These are natural fibers that consist of cellulose and moisture. So, need to treat before mixing with other materials in ECC [18,19]. Alkaline treatment is one of the acceptable techniques for treating natural fibers. In this method, fibers are cleaned and dipped in a 6% concentration of NaOH solution for 30min. These are neutralized with 2% of HCL before being dried for 3h at 80°C in the oven based on past researchers [19]. After that, fibers are cut in 12mm lengths for suitability with PVA fibers that do not affect the composite's mixing process.

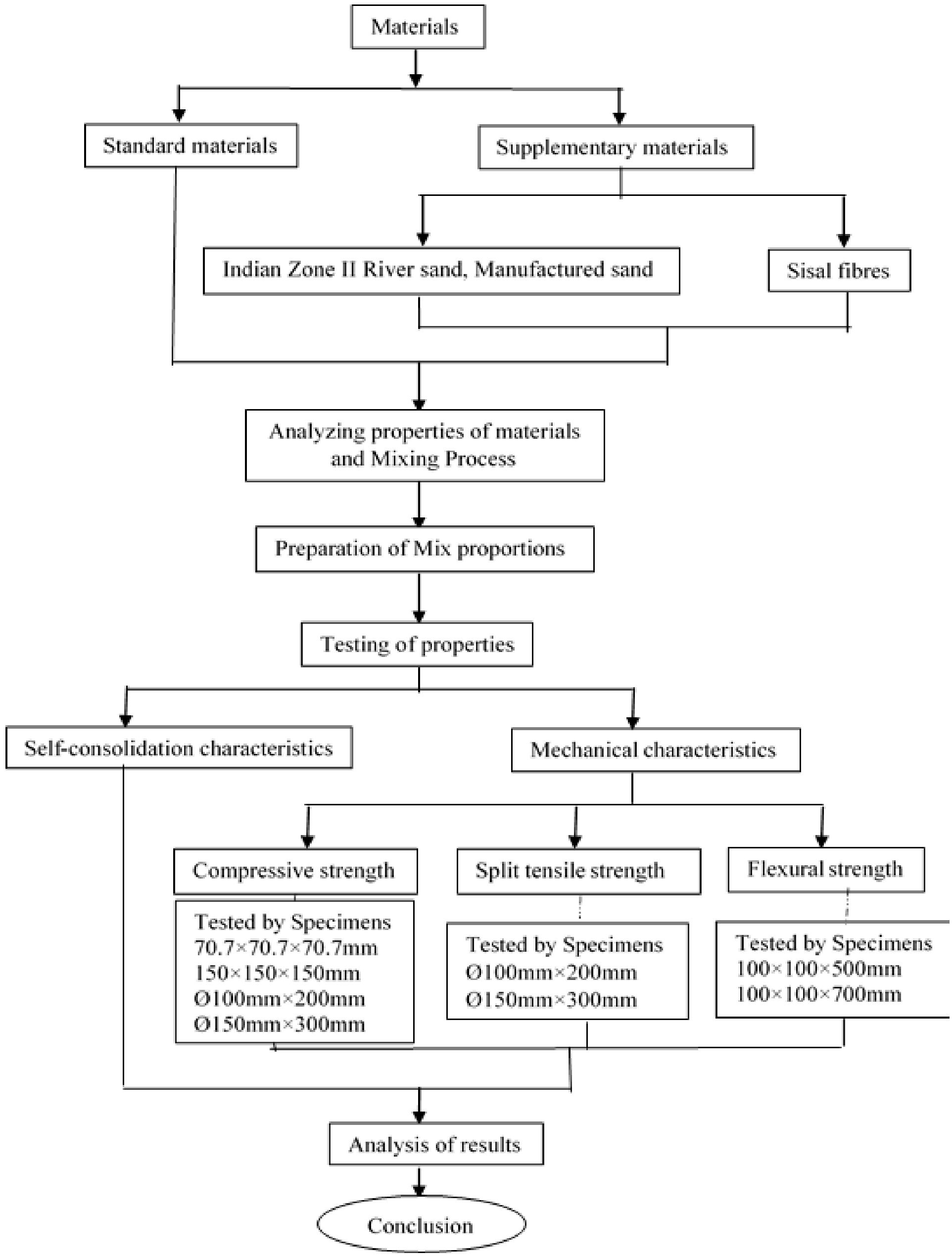

Fig. 1 Methodology with various factors

Fig. 2 Untreated PVA fibres

Fig. 3 Sisal Plant [17]

Fig. 4 Treated (or) Oiled PVA fibres

Fig. 5 Treated Sisal fibers

2.2. Mixing Process

This is one of the critical factors that will decide the performance. In this study, the mixing process was considered based on past researchers [20,21] and our experimental studies. A pan mixer with 120L capacity and 1440rpm was used to mix the materials at a constant speed. Initially, cement, fly ash, and fine aggregates are mixed for 3min. For this mix, PVA fibers are added and mixed for 2min. Later, the Turbopol CEA50 and water are added and blended for 3min. This mixing process was used for the preparation of samples to analyze the characteristics of ECC.

2.3. Mix proportions

The mixing proportions mentioned in the Table 3 were considered in this study to determine the impact of the specimen's properties, hybridization of fibers, and locally available fine aggregates. These mixtures are the local sand based (50% of River sand + 50% of M-sand) and sisal fiber (1% PVA+1% Sisal fibers) based mixes. The specimens of cube (70.7×70.7×70.7mm, 150×150×150mm), cylindrical (Ø150mm×300mm, Ø100mm×200mm), and prism specimens of 100mm×100mm×500mm, 100mm×100mm×700mm were prepared with that mix proportions. The PVA fibres replaced by Sisal fibers based on volume.

Table 3. Mix proportions

Mix	Ingredients (kg/m^3)									
	CE	F	water	River sand	M-sand	PVA	SS	PCE	F/C	w/b
1	483	676	320	213	214	26	-	4.55	1.4	0.27
2	483	676	320	213	214	13	13	4.55	1.4	0.27

PVA: Polyvinyl alcohol, SS: Sisal fibres, CE: Cement, F: fly ash, w/b: water/ binder, PCE: Polycarboxylate ether

2.4. Curing of Specimens

Water curing under air submersion was preferred in this study based on past research investigations. Zhu et al. [22] analyzed the impact of different curing conditions such as water curing under air submersion and room-air storage on the hardening characteristics of ECC. These characteristics were improved with the water curing under air submersion compared to the room-air storage. This indicates that the appropriate curing conditions are water curing under air submersion. After 28 days of curing, all the specimens are placed in a room for 1 to 2 days before testing to analyze the characteristics of ECC.

3. Experimental Tests:

3.1. Flowability and Self-consolidation Test

The fresh properties were determined by the T_{50} slump cone test, as per ASTM 1611 [23]. For this, a slump cone was placed on the steel plate of 900mm×900mm. After pouring of composite into a slump cone, allowed to spread on the steel plate. The deformability factor (DF) for all these mixtures was measured based on the following formulae mentioned in Eq (1), and that should be less than 2.75

$$DF = \frac{(D1 - D0)}{D0} \tag{1}$$

where D_1=Average diameter of the two orthogonal, D_0= slump cone's bottom diameter

3.2. Hardening Properties

3.2.1. Compressive Test

The compressive characteristics were determined under a compression testing machine with a 140kg/cm^2/min rate of loading as per IS 516-2013 [24]. For this, cubes 70.7mm×70.7mm×70.7mm, and 150mm×150mm×150mm and cylindrical specimens of Ø100mm×200mm, Ø150mm×300mm were used. These two cube specimens are considered to determine the impact of the cube's size on the compressive characteristics of the composite. The two sizes of cylindrical specimens were used to assess the impact of the cylinder's size on the composite. From this, the compressive ratio (compressive strength of cube to cylinder) was also determined. The compressive setup for this study was shown in Fig. 6(a), Fig. 6(b).

3.2.2. Split Tensile Test

The split tensile properties of the composite mixes were determined under the split tensile testing machine with the 1.2N/mm^2/min as per IS 5816-1999 [25]. For this, cylindrical specimens of Ø100mm×200mm, and Ø150mm×300mm were used. These two cylindrical specimens are considered to determine the impact of the specimen's size on the split tensile properties. The split tensile test setup for this analysis was shown in Fig. 6(C).

3.2.3. Flexural Test

The flexural properties were determined under the flexural testing machine as per IS 516-1959 [26]. For this, prism specimens of 70.7mm×70.7mm×70.7mm 150mm× 150mm×150mm were used. These two prism specimens are considered to determine the impact of the specimen's size on the flexural properties of the ECC. The flexural test setup for this analysis was shown in Fig. 7.

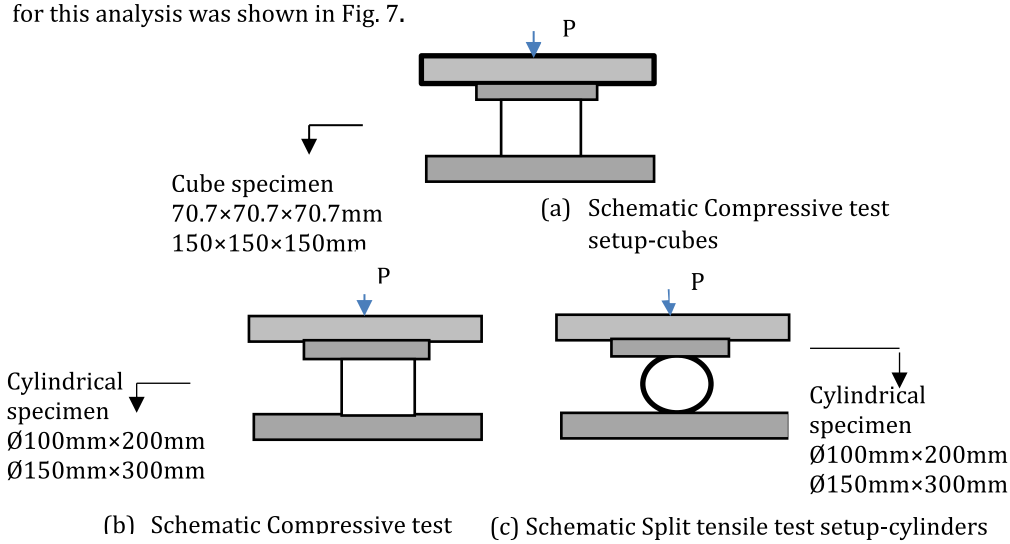

Fig. 6 Specimens under compression and split-tensile test

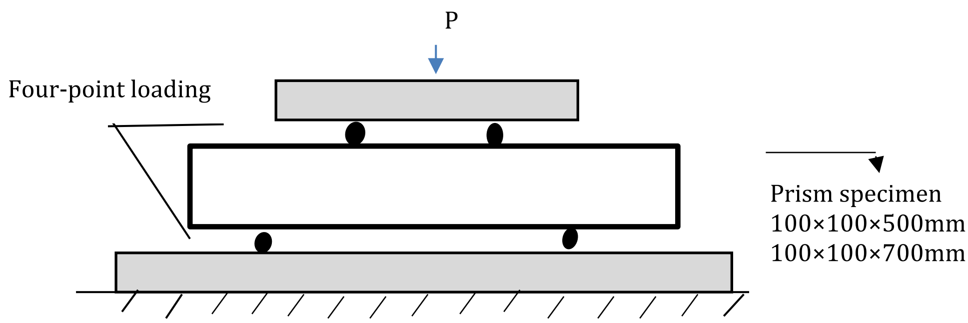

Fig. 7 Schematic representation of specimens under Flexural test

Where, P=Specimens (cubes, cylinder, prisms) under loading

Fig. 6 represents the schematic setup of compression and split tensile test. The cube specimens of 70.7mm×70.7mm×70.7mm and 150mm×150mm×150mm and cylindrical specimens of Ø100mm×200mm and Ø150mm×300mm were considered for compression test. These cylindrical specimens were also used for analyzing split tensile characteristics. Fig. 7 represents the schematic setup of the flexural test. For this, prism specimens of 100mm×100mm×500mm and 100mm×100mm×700mm were considered. The four-point loading was applied to these specimens to study the characteristics of ECC. All these test setups were followed and applied loading conditions were based on Indian standards.

3.3. Durability Test

RCPT test was conducted in this study to determine the durability of ECC. For this, Ø100mm×50mm size disc specimens were used to determine these characteristics in terms of chloride ion penetration as per ASTMC1202 [27]. The NaOH and NaCl solutions are poured into the RCPT reservoirs to measure the intensity of chloride ions. The schematic RCPT test setup is mentioned in Fig. 8.

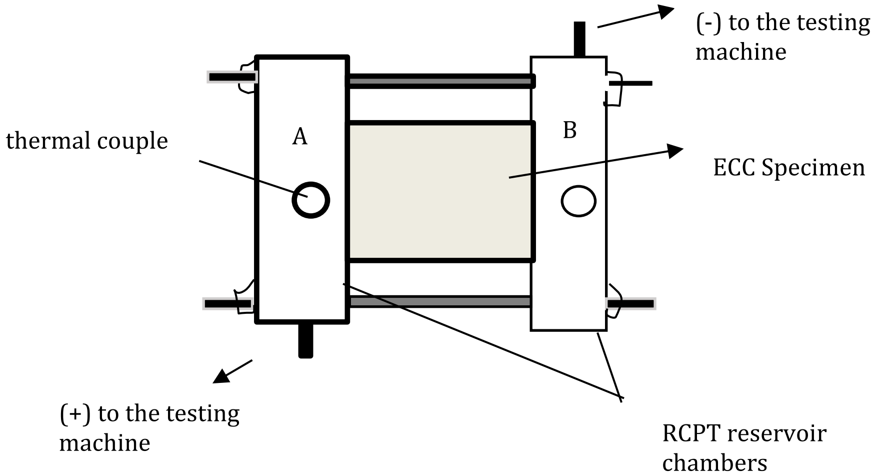

Fig. 8 RCPT schematic test setup

Fig. 8 illustrates the schematic test setup of the RCPT. It has an ECC specimen between the two chambers, and silica sealant was used to avoid any gaps between them. Chambers A and B are the reservoirs that contain 3% NaOH solution and 3%NaCl solutions, respectively. These solutions are poured into the chambers to measure the intensity of chloride ion penetration. This indicates the durability of the composite mixtures.

4. Test Results and Discussions

4.1. Flowability and Self-Consolidation Characteristics

The fresh properties of the composite were measured with the T_{50} slump cone test. These results for the local sand (50% of River sand+50% of M-Sand) based mixes and sisal fibre-based (1% of PVA fibres+1% of sisal fibres) are mentioned in the Table 4. The sisal fiber based mixes also showed good self-consolidation (S.C.) characteristics. The D.F. <2.75 indicates good S.C. (based on the Li, 2008).

Table 4. Fresh properties of ECC mixtures

Mix id	Mix-1	Mix-2
Slump flow	510	505
T_{50} (sec)	2.52	2.55
D.F.	1.55	1.525
S.C.	Good	Good

Where T50(sec) indicates flow time, D.F. indicates Deformability factor, S.C. indicates self-consolidation. For good self-consolidation characteristics, the deformability factor <2.75

The composite's flowability was slightly reduced due to the addition of sisal fibres, which were treated by alkaline treatment. The flow time of the composite is increased with the replacement of sisal fibres from mix-1 to mix-2. But all the mixtures showed good-self consolidation properties.

4.2. Mechanical Characteristics

4.2.1. Compressive Characteristics

The compressive properties were determined by cube specimens of 70.7mm×70.7mm×70.7mm and 150mm×150mm×150mm, cylindrical specimens of Ø100mm×200mm and Ø150mm×300mm. These test results were shown in Fig.9 to Fig.13. These compressive characteristics were reduced with the size of specimens. The compressive strength of the Mix-1 local sand based mixes is reduced by 0.478% from the 70.7mm×70.7mm×70.7mm specimen to 150mm×150mm×150mm specimens. This is a very marginal decrease in the strength. Mix-1's compressive characteristics were also marginally reduced from cylindrical specimens Ø100mm×200mm to Ø150mm×300mm. The compressive strength for the Mix-2 (1% PVA fibres + 1% Sisal fibres) mixes is reduced marginally from 70.7mm×70.7mm×70.7mm specimen to 150mm×150mm×150mm specimens. Mix-1's compressive characteristics were also reduced marginally from cylindrical specimens Ø100mm×200mm to Ø150mm×300mm. It indicates that the impact of size of the specimens on the characteristics is negligible. So small-size specimens such as the cube, and cylindrical specimens can be used to analyse the compressive characteristics of ECC. But the shape of specimens is needed to consider for the study of composite' compressive strength. These characteristics are reduced by 30-35% from the cube specimens (70.7mm×70.7mm×70.7mm, 150mm× 150mm×150mm) to cylindrical specimens (Ø100mm×200mm, Ø150mm×300mm). The compressive ratio (compressive strength of cube to compressive strength of cylinder) based on these specimens for these ECC mixtures is between 1.45 to 1.6. These cube specimens are considerable in the design of beams and cylindrical specimens are significant for columns.

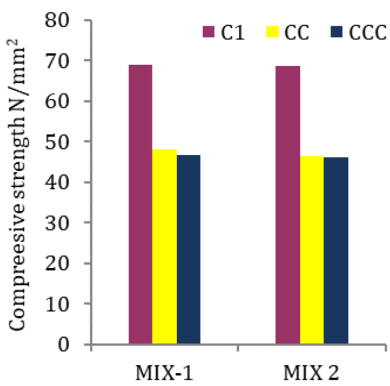

Fig. 9 Compressive strength of (C1 with CC, CCC)

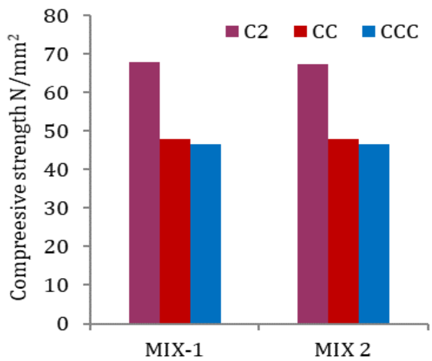

Fig. 10 Compressive strength of (C2 with CC, CCC)

Where C1 denotes 70.7×70.7×70.7mm, C2 denotes150×150×150mm, CC denotes Ø100mm×200mm, CCC denotes Ø150mm×300mm

Fig.9 represents the impact of cube specimen 70.7mm×70.7mm×70.7mm and cylindrical specimens Ø100mm×200mm, Ø150mm×300mm on the characteristics of Mix-1,2. Fig.10 represents the impact of cube specimens 150mm×150mm×150mm and cylindrical specimens Ø100mm×200mm, Ø150mm×300mm on the characteristics of Mix-1,2. The compressive characteristics are slightly impacted by the size of specimens. But are highly influenced by the specimens 'shape.

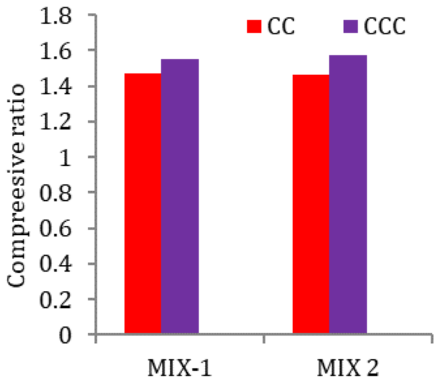

Fig. 11 Compressive ratio (C1 with CC, CCC)

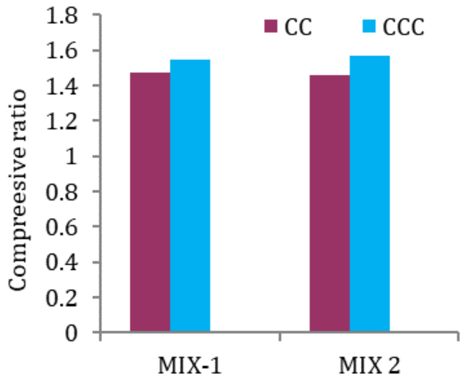

Fig. 12 Compressive ratio (C2 with CC, CCC)

Fig. 11 and Fig. 12 illustrates the compressive ratio of the cube specimens to cylindrical specimens. These compressive ratios of Mix-1 and Mix-2 are lies between 1.45 to 1.6. The compressive ratio equation mentioned below can be implemented to analyse the impact of hybridization of fibres, specimens' properties, and local fine aggregates on the compressive characteristics of ECC.

$$A = B(x) + C \quad (2)$$

A= Cube's compressive strength, B=cylindrical compressive strength, X=compressive ratio =1.45 to 1.6, C=Compressive strength (1 to 3N/mm^2) due to miscellaneous factors,

For this experimental analysis C=0

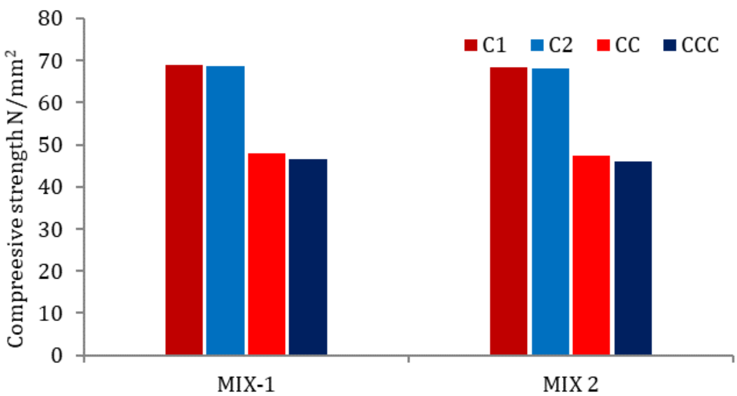

Fig. 13 Compressive characteristics of ECC mixtures

Fig.13 represents the impact of hybridization (sisal fibres and PVA fibres), locally available fine aggregates (river sand, M-sand), and specimens' properties (shape, size) on the compressive characteristics of ECC. In this, the two cube (70.7mm×70.7mm×70.7mm, 150mm×150mm×150mm) and cylindrical Ø100mm×200mm, Ø150mm×300mm) compressive strengths for mixes were mentioned. It showed that small-sized cubes and cylindrical specimens can be considered for analysing the compressive characteristics but the shape of specimens and compressive ratio needed to be considered.

4.2.2. Split tensile characteristics

The split tensile properties were determined by the cylindrical specimens of Ø100mm×200mm and Ø150mm×300mm. These test results were shown in Fig.14. These split tensile characteristics were reduced by the size. The split tensile characteristics of Mix-1 were reduced by 7.41% from the cylindrical specimens Ø100mm×200mm to Ø150mm×300mm. The split tensile characteristics of Mix-2 were reduced by 7.69 % from the cylindrical specimens of Ø100mm×200mm to Ø150mm×300mm. These characteristics are marginally reduced from Mix-1 to Mix-2. It indicates that the size of cylindrical specimens can highly influence the split tensile characteristics.

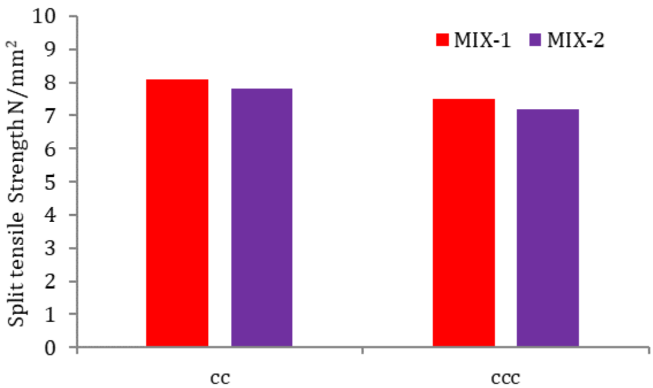

Fig. 14 Split characteristics of ECC mixtures

Fig.14 represents the influence of hybridization (sisal fibres and PVA fibres), locally available fine aggregates (river sand, M-sand), and specimens' properties (shape, size) on the split tensile characteristics of ECC. In this, the cylindrical Ø100mm×200mm Ø150mm×300mm) split tensile strengths for mixes Mix-1 and Mix-2 were mentioned. This showed that appropriate size cylindrical specimens (Ø150mm×300mm) could be considered for analyzing the split tensile properties.

4.2.3. Flexural Characteristics

The flexural properties were determined by the prism specimens of 100mm×100mm×500mm, 100mm×100mm×700mm. These test results were shown in Fig.15. These flexural characteristics were reduced by the size. The flexural properties of Mix-1 were reduced by 5.21% from the prism specimens 100mm×100mm×500mm, to 100mm×100mm×700mm. The flexural characteristics of Mix-2 were reduced by 5.09% from the prism specimens 100mm×100mm×500mm to 100mm×100mm×700mm. It indicates that the size of prismatic specimens negligibly impacted the flexural characteristics.

Based on this, the relation between the split tensile and flexural characteristics of ECC mixtures was mentioned in Eq (3).

$$\mathrm{Ff} \quad = \mathrm{Fs(y)} + \mathrm{L} \tag{3}$$

Where F_f=Flexural characteristics of ECC, Fs= Split tensile characteristics of ECC, Y= Factor of split tensile characteristics to flexural characteristics=1.5 to 1.7, L= Flexural strength (0.1to 0.4N/mm^2) due to miscellaneous factors, for this study L=0

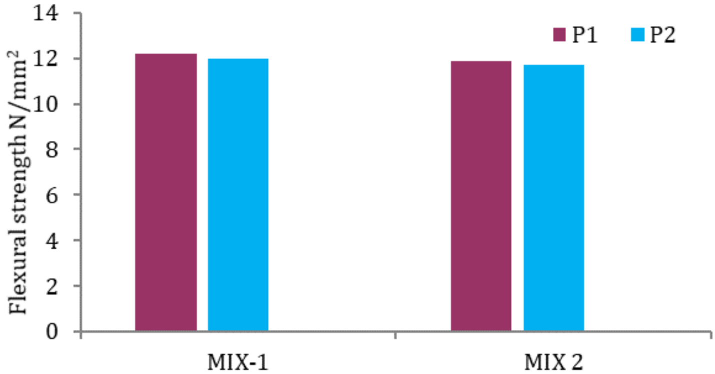

Fig. 15 Flexural characteristics of ECC mixtures

Where P1 denotes prismatic specimen-100mm×100mm×500mm, P2 denotes prismatic specimen-100mm×100mm×700mm

4.3. Durability Characteristics

To analyze the durability characteristics of ECC mixtures, the RCPT test was conducted. These characteristics are measured as the intensity of chloride ion penetration. For this, Ø100×50mm size specimens were cast and placed in the RCPT apparatus to analyze the impact of sisal fibres on the local sand (50% of river sand + 50% of M-sand) based mixes. These mixtures showed that negligible increase in chloride ion penetration, the microstructure (SEM and XRD) of these mixtures was shown in Fig.16 to Fig.18. The microstructure of these mixes is almost similar and densified. So, sisal fibres can be used with partial replacement of PVA fibres in the local sand (river sand + M-sand) based composite mixes.

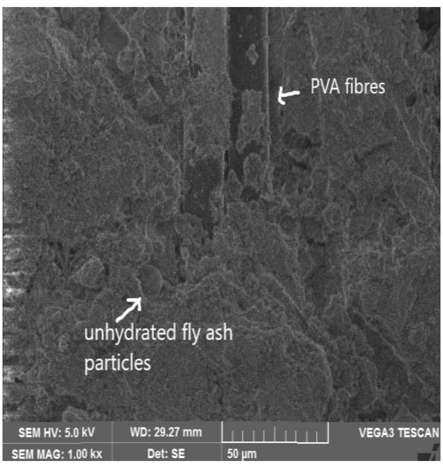

Fig. 16 SEM image of Mix-1

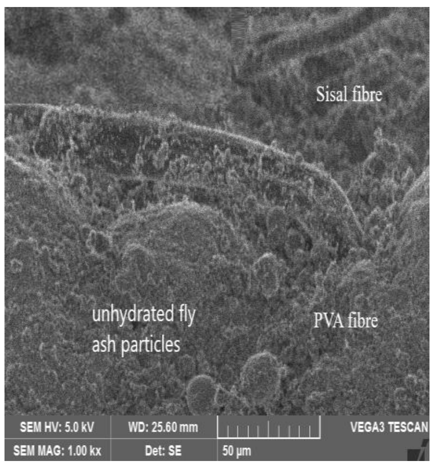

Fig.17 SEM image of Mix-2

The hydration of materials and arrangement of fibres and its properties are responsible for slight difference in the portlandite (P), quartz (Q) content (unhydrated particles) in the matrix of composite. It is responsible for the slight difference in durability. This kind of phenomenon and XRD pattern is validated with the (Roychand et al., 2016) past researcher study [28]. The arrangement of fibres and hydration of particles (formation of C-S-H and CH gels) responsible for performance. Based on these results, sisal fibres can use an alternative to PVA fibres for prepare Eco-friendly ECC.

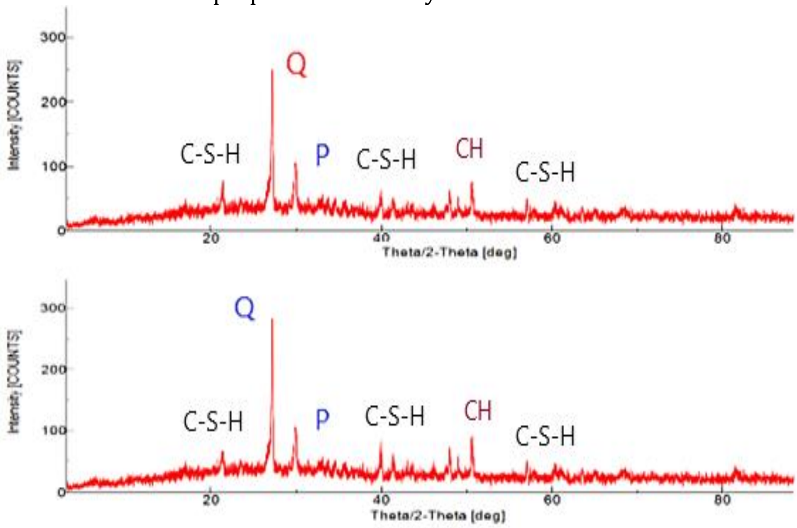

Fig.18 XRD of ECC-Mixes (Top Mix-1, Bottom Mix-2)

5. Conclusions

Based on the experimental analysis on the performance of Synthetic fibres (PVA) and natural (Sisal) fibres-based composites, the following conclusions are given.

- The characteristics of ECC-Mixes mainly depends on the properties of specimens and materials. To analyse the impact of sisal fibres on the characteristics, different specimens are considered. The cube specimens of (150mm×150mm×150mm and 70.7mm×70.7mm×70.7mm), cylindrical specimens (Ø100×200mm and Ø150×300mm), prism specimens (100mm×100mm×500mm and 100mm×100mm×700mm) considered.
- The compressive characteristics were slightly decreased by the increased size of specimens. But highly influenced by the shape of specimens. These characteristics were decreased by 30-35% from cube specimens to cylindrical specimens. The compressive ratio (compressive strength of cube specimens to cylindrical specimens) of these mixes is between 1.45 to 1.6.
- Specimens' size moderately influenced the split tensile properties. These characteristics were reduced by 7-10% from the cylindrical specimens of Ø100×200mm to Ø150×300mm. So appropriate size of cylindrical specimen is Ø150×300mm for analysing the split tensile characteristics. At this, the minimum required strength is determined. The flexural characteristics were slightly influenced by the size of the specimens.
- But these mechanical characteristics were slightly reduced with sisal content (or) dosage of sisal fibres. Shape of specimens highly influenced the compressive characteristics compared to their size. The flowability slightly reduced by usage of sisal fibres compared to PVA fibres based mixes. All these considered mixes showed good self-consolidation characteristics (Deformability factor (D.F.) <2.75 based Li, 2008).

- However, durability characteristics are also slightly reduced from Mix-1 to Mix-2. These test results indicate that the sisal fibres can use an alternative to traditional PVA fibres. The performance of these mixes is validated with the past researcher (Roychand et al, 2016) study. By observing Scanning Electron Microscopy (SEM) and X-ray diffraction analysis (XRD) results, the arrangement of fibres and Hydration of particles are responsible for these characteristics.

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Abbreviations:

ECC	Engineered Cementitious Composite
M-Sand	Manufactured sand
PVA	Poly Vinyl alcohol
D.F.	Deformability factor
RCPT	Rapid chloride penetration test
SEM	Scanning Electron Microscopy
XRD	X-ray diffraction Analysis

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