EVALUATION OF STRENGTH AND DURABILITY OF NATURAL FIBRE REINFORCED HIGH STRENGTH CONCRETE WITH M-SAND

SHANMUGA PRIYA T, THIRUMALINI S *
Department of Structural and Geotechnical Engineering, VIT University, Vellore, India

The experimental investigation was carried out to study the variation in strength and durability properties of high strength concrete incorporated with sisal, banana and coir fibres. In this study, three different percentage 0.5%, 1% and 1.5% by volume of sisal , banana and coir fibres were casted and results compared with control mix. The strength properties such as compressive strength, splitting tensile strength and flexural strength and durability properties like water absorption, sorptivity and rapid chloride permeability was studied. Test results show that, the addition of sisal , banana fibre and coir fibre resulted in the enhancement of compressive strength, splitting tensile strength and flexural strength of concrete in the range of 4% to 10%. The optimum mix was arrived as 1% sisal and banana fibre and 0.5% coir fibre. The durability properties of optimum mix like water absorption, sorptivity and Rapid Chloride Penetration Test (RCPT) values have better performance compared to control mix due to its pore filling effect of natural fibres making the concrete denser.

Keywords: *Natural Fibre, Strength, Durability, High Strength Concrete*

1. Introduction

Concrete is the most widely used construction material world-wide. Because of its adaptability and low cost it lends itself to a wide range of applications, from buildings to bridges and other infrastructure facilities [1]. Its main disadvantage is its low tensile strength and fracture toughness. In order to compensate for the low tensile strength, it has been traditionally reinforced primarily with steel reinforcing bars. The addition of steel reinforcement to concrete significantly increases its strength, but to produce a concrete with homogenous tensile properties and to control the initiation and growth of micro cracks, uniformly distributed and randomly oriented short fibres are necessary [2]. Fibres made of a variety of materials, such as steel, glass, carbon and other polymeric materials are used to improve the fracture toughness. However, these fibres are resistant to biodegradation and can decrease the service life of the concrete structure. Natural fibres such as coir, jute, sisal and banana have advantages in comparison with man-made fibres in that they are renewable and biodegradable. Natural fibres enhance the properties of concrete, control the propagation of cracks, usually increase tensile strength, toughness and ductility of the elements in which they are used. Moreover, these fibres have low density, energy-efficient, economical and eco-friendly [3,4].

Many authors investigated the mechanical and durability characterization of sisal fibres and coconut fibres in cement composites [5-7]. According to these surveys, natural or vegetable fibres enhance the mechanical, thermal and physical performances of cement-based composites when added to the cementitious matrix, as they increase their flexural strength, and impact resistance, reduce shrinkage on drying and thermal conductivity. The work performed by Merlini et al. [8] investigated prediction of critical fibre length, tensile strength of the fibre and composite and the results indicated that the influence of alkali treatment on the banana fibre and its polyurethane reinforced composite improves the interfacial adhesion between fibre and matrix. Pothan et al. [9] studied the mechanical properties of banana fibre reinforced polyester with jute, sisal and coir reinforced composites. Comparative analysis with other natural fibres shows banana fibre composite has superior mechanical properties than other composites.

Ozge Andic-Cakir et al. [10] investigated mechanical properties of coir fibre–cementitious composites. They found that the alkali treatment upgrades the fibre–matrix contact resulting in enhancement of the mechanical properties, especially flexural strength and toughness at 0.4%,

* Autor corespondent/*Corresponding author*,
E-mail: thirumalini.selvaraj@vit.ac.in

0.6% and 0.75% fibre dosages. Fibre incorporation affects water absorption capacity of mortars, enhances their mechanical and thermal properties and decreases their unit weight. Ramakrishna and Sundararajan [11] conducted the investigations for measuring the impact resistance, residual impact ratio, crack resistance ratio on mortar slabs with cement-sand ratio of 1:3. Four types of natural fibres such as coir, sisal, jute and Hibiscus cannabinus having three different fibre lengths 20 mm, 30 mm and 40 mm with four different fibre contents such as 0.5%, 1.0%, 1.5% and 2.0% by weight of cement was used in their study. From this test results, it was concluded that 2% coir fibres content and a fibre length of 40 mm showed best performance among all tested fibres. Pramasivan et al. [12] studied coconut fibre reinforced corrugated slabs and concluded that the coconut fibre of volume fraction of 3%, fibre length of 25 mm with a flexural strength of 22 MPa resulted better resistance in thermal conductivity and absorption coefficient compared with conventional asbestos boards. Mechanical and tensile properties of sisal fibre reinforced polymer composites studied by Mukherjee & Satyanarayana [13]. They concluded that both tensile strength and percent elongation decrease with fibre length increases from 15 mm to 65 mm, whereas Young's modulus increases with fibre length. Li et al. [14] studied the bending tests on slab specimens with different fibre volume fraction. They used the coir mesh reinforced mortar produced by fibre surface treatment with a wetting agent for nonwoven coir mesh matting and they concluded that the composites reinforced with three layers of coir mesh having fibre content of 1.8% resulted in a 40% improvement in the maximum flexural stress.

Yan Li et al. [15] reviewed the properties of sisal fibre interface between sisal fibre and matrix, sisal-fibre-reinforced composites properties and their hybrid composites They concluded that the improvement of mechanical and physical properties of sisal fibre depend on fibre diameter, gauge length, strain rate and temperature. From their studies, sisal-fibre-reinforced composites the energy-absorption mechanisms during impact fracture shows that fibre pull-out and interface fracture are the major contributors to the high toughness of these composites. Indara Soto Izquierdo et al. [16] investigated the mechanical behaviour of masonry elements made of concrete and natural sisal fibres. Compression tests were carried out on individual hollow blocks, as well as on prisms and wallettes made of hollow blocks. They found that low elastic modulus sisal fibres with 1% of in concrete volume become effective and leads to an increased absorption of energy and gives the wallettes the ability to withstand load increments after cracking.

Due to the growth of construction industry and major infrastructure projects, there is a huge demand for natural sand, it becomes necessary to explore the possibilities of finding a sustainable and viable alternative to minimize river sand extraction. Previous researches have shown that good quality of normal and high strength concrete can be made using manufactured sand [17-19]. A review of past studies indicates that in spite of numerous researches done on natural fibres in reinforced cement composites with natural sand little attention has been paid to evaluate the durability and mechanical behaviour of natural fibres on reinforced concrete with M-Sand which is commonly used for the precast and concrete composites applications. There is little previous research about the effect of sisal, coir and banana fibre incorporated into mechanical properties of composites [20-24]. But no elaborative studies have been carried out so far on durability aspects of natural fibre in concrete, still scarce. Therefore, this study focuses on understanding of the three different natural fibres such as sisal, banana and coir effect on durability and strength aspects of High Strength Concrete with M-Sand by experimental programs. The strength properties like compression strength, split tensile strength and flexural strength and the durability properties like saturated water absorption, sorptivity and rapid chloride permeability has been found and the results were compared to conventional concrete without fibre.

From the earlier studies [25,26], it was found that the optimum volume fraction of fibres in concrete was 1.5% while without water reducing admixture. Also the maximum aspect ratio was restricted to 400 and in order to avoid the balling effect on concrete during mixing, the volume fraction of fibres was restricted to 2.0%. Hence, in the present investigation, the High Strength Concrete (HSC) mix with the dosage of 0.5%, 1% and 1.5% with sisal, banana and coir fibres and aspect ratio of 300 were selected. It was the purpose of the work presented here to identify optimum fibre dosage of three different fibres that improve the strength as well as durability properties of high strength concrete in aggressive environment.

2. Experimental Investigation

2.1.Materials

2.1.1. Cement

53 grade ordinary portland cement conforming to IS: 12269 [27] of specific gravity 3.15 was used. The cement was tested based on Indian standards IS 4031 [28] procedure and the chemical composition were presented in Table 1.

2.1.2. Fine aggregate

M-Sand used in this investigation was well graded and conforming to Zone III as per IS 383 [29]. The fineness modulus and specific gravity of sand used is 2.86 and 2.65 respectively. The Bulk density and water absorption of M-Sand is 1748 kg/m^3 and 0.8% respectively.

Table 1

Chemical composition of ordinary Portland cement

Component	SiO_2	Al_2O_3	MgO	Fe_2O_3	CaO	Na_2O	K_2O	LOI
Value in %	23.5	5.2	0.8	3.5	66.8	0.25	0.48	2

LOI – Loss of Ignition

Table 2

Properties of natural fibres

Fibre type		**Sisal**	**Banana**	**Coir**
Fibre length (mm)		60	45	30
Fibre diameter (mm)		0.2	0.15	0.1
Density (kg/cm^3)		1.5	1.3	1.2
Tensile strength(N/cm^2)		250	500	175
Elongation (%)		30	7	3
Elastic -modulus (GPa)		7.83	1.4	4.3

(a) **Sisal** **(b) Banana** **(c) Coir**

Fig. 1 - Types of Fibres.

Table 3

Properties of natural fibres

S.No.	No. of Specimens	Size	Test to be conducted
1	60	150 mm cubes	Compressive strength
2	30	150 mm diameter and 300 mm height cylinders	Split tensile strength
3	30	500 mm x 100 mm x 100mm beams	Flexural strength
4	30	100 mm cubes	Water absorption
		150 mm cubes	Sorptivity test
5	30	50 mm thick, 100 mm diameter cylinder	Rapid chloride permeability test

2.1.3. Coarse aggregate

Crushed granite coarse aggregate conforming to IS: 383 [29] of maximum size 20mm having the specific gravity of 2.72 was used. The bulk density and the water absorption of the aggregates were 1550 kg/m^3 and 1% respectively.

2.1.4. Fibres

Locally available treated fibres are used and the physical properties of sisal, banana and coir fibre with aspect ratio of 300 was presented in Table 2 and Figure 1.

2.2. Concrete mix design & testing methods

Mix design for M40 grade of concrete was done as per the guidelines specified in the Indian Standard code IS 10262: 2009 [30] and the quantity of cement, coarse aggregate, fine aggregate and water were found out for one cubic meter of concrete. The mix ratio was used in this investigation is 1: 1.1: 2.08: 0.32. Ten concrete mixtures with three natural fibres namely, sisal, banana and coir were casted. For each fibre three percentages of fibre dosage, 0.5%, 1% and 1.5% and conventional mix were casted. The conventional concrete named as CC and S, B and C are the notation given for sisal, banana and coir and 1, 2 and 3 denotes fibre dosage 0.5%, 1% and 1.5% respectively. Cubes of size 150 mm x 150 mm x 150 mm, cylinders of size 150 mm diameter and 300 mm height and beams of size 500 mm x 100 mm x 100mm were casted for each mix. A total of 210 specimens were casted and tested as per the guidelines and the details are presented in Table 3.

The cubes used for compressive strength tested at the age of 7 & 28 days. Cylinders and beams for splitting tensile strength and flexural strength were tested at the age of 28 days. Water Absorption Test, Sorptivity and Rapid Chloride Permeability tests were done at the age of 28 and 90 days.

2.3. Test program

Compressive strength test was conducted at the age of 7 and 28-day in accordance with BS EN 12390: Part 3 [31]. Test was conducted using Compression Testing Machine (CTM) of capacity 2000 KN. Split tensile strength of concrete was

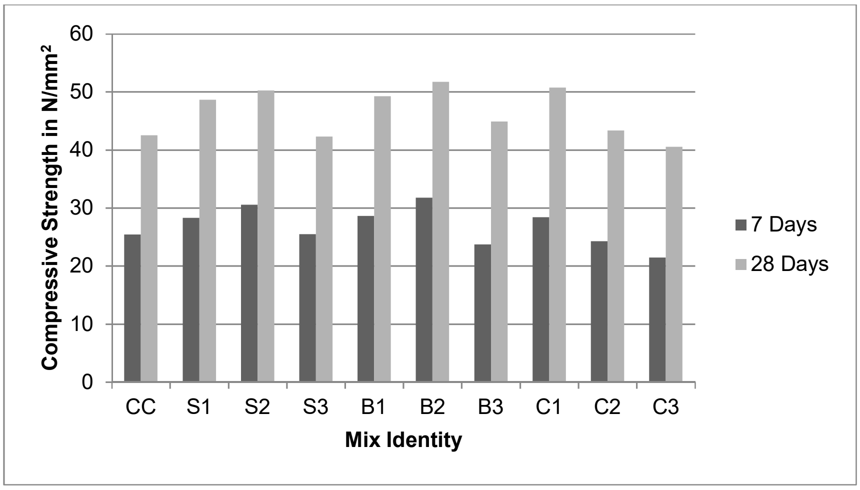

Fig. 2 - Compressive Strength of High Strength Concrete.

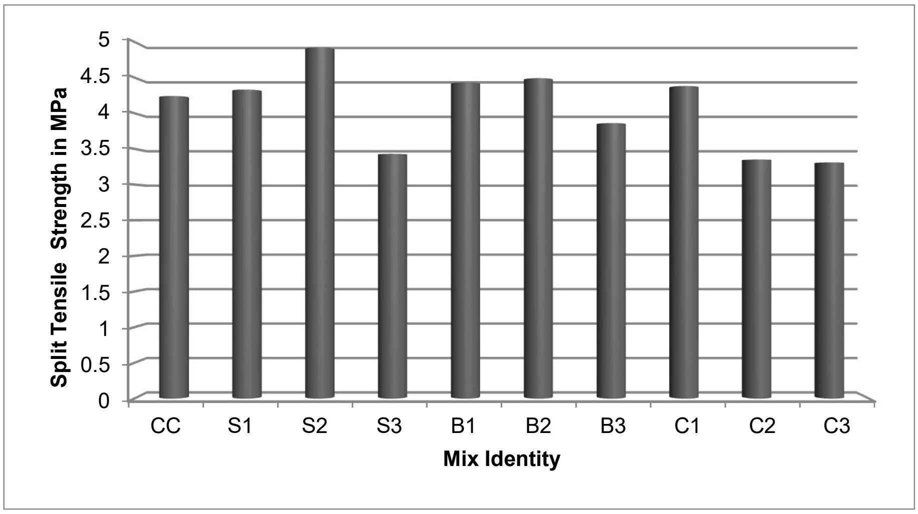

Fig. 3 - Split tensile Strength of High Strength Concrete.

carried out conforming to IS: 516 [32], cylinders were tested using above machine. Flexural strength of concrete was conducted out conforming to IS: 516 [32], beams were tested using Flexure Testing Machine (FTM) of capacity 100 KN. The water absorption was determined on 100 mm cube specimen at the age of 28 days curing as per ASTM C- 642 [33] by drying the specimens in an oven at the temperature of 105°C to constant mass and immersing in water after cooling to room temperature. The difference between the water saturated mass and oven dry mass expressed as a percentage of oven dry mass gives the saturated water absorption.

The sorptivity test measures capillary suction of concrete when it comes in contact with water. The test was conducted on 150 mm cube specimens in accordance with the ASTM C 1585 [34]. Two specimens were cured under water for 28 days and tested at 28 days and 90 days of age. The specimens were oven dried until constant weight and then put in contact with water in one surface and sealing the other surfaces. Mass gain due to sorption was measured at definite intervals for the first six hours. The sorptivity S is the slope of the best-fit line to the plot of absorption against square root of time. The rapid chloride permeability test was conducted to assess the concrete equality as per ASTM C 1202 [35]. A potential difference of 60 V DC was maintained across the specimen. One of the surfaces was in contact in a sodium chloride solution (NaCl) and the other with a sodium hydroxide solution (NaOH). The total charge passing through 30 minutes interval for the duration of six hours was measured, indicating the degree of resistance of the specimen to chloride ion penetration.

3. Results and Discussion

3.1. Compressive strength of concrete

Compressive strength test results of concrete mixtures with natural fibres at the age of 7 and 28 days are shown in Figure 2.

From the Figure 2, it is observed that, all the mixes shows increase in strength over the curing age period. Among all the mixes, banana fibrous concrete mix possesses the highest strength at all the ages. Also from above Figure it was noted that the 7 and 28 days compressive strength of 1% sisal fibre was close to 0.5% of coir fibre which was

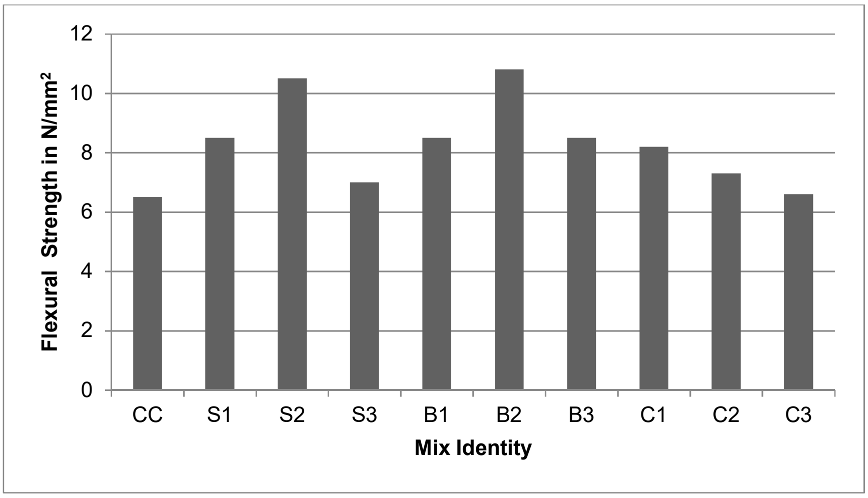

Fig. 4 - Flexural Strength of High Strength Concrete.

slightly lower than 1% of banana fibre. The compressive strength of banana fibre is higher than other two fibres. The compressive strength of concrete increased by 4%, 6.72% and 4.6% in presence of 1% sisal, 1% banana and 0.5% coir respectively than that of conventional concrete at the age of 28 days. Generally the use of natural fibres in composites such as mortar or concrete are increasing their certain properties ie tensile strength, shear strength, toughness and/or combinations of these [36]. However, in this study compressive strength levels have shown an increase that is comparable to conventional concrete. The reason is related to the type and dosage of fibres and further research is necessary to understand this fibre–matrix behaviour of such mixtures through microscopic evaluation. From the test results it was also noted that compared with conventional concrete the all the mixes the strength was increased because of fibre dosage and void filling ability of M-Sand. The micro fines present in the M-Sand also can improve fine-particle packing, thus increase the density of paste matrix and interfacial transition zone in hardened concrete [37], and improve the pore structure of concrete.

3.2. Split tensile and flexural strength of concrete

The results of split tensile and flexural strength of different mixes with repect to reference mix was depicted in Figure 3 and Figure 4.

From the Figure 3, it is clearly noted that, there is no much variation in enhancement of tensile strength of different fibre dosages. Among all, here 1% sisal fibre concrete specimen possesses the highest tensile strength. The tensile strength of conventional concrete is 4.24 MPa at 28 days of curing 1% sisal, 1% banana and 0.5% coir fibre give the 28 days tensile strength as 4.92 MPa, 4.49 MPa and 4.38 MPa, respectively. Hence 1% of sisal and banana and 0.5% of coir fibre as considered as optimum percentage beyond that there is a decrease in strength. From the Figure 3, it is also observed that, addition of 1% sisal fibre exhibits little bit more tensile strength than conventional and all other mixes.

From results it can be seen that beyond 1% replacement of all fibres replacement, strength was not quite satisfactory. The reason is as the percentage of fibre increases the interaction between the fibres inside the composite increases i.e. there will be higher fibre to fibre contact which leads to poor interfacial bonding between the fibre and the matrix. Due to this poor interfacial bonding effective load transfer will not takes place and leads to failure quickly [38]. According to Faruk et al. [39], mechanical properties of plant fibres (jute, kenaf, sisal, coir, bamboo etc.) have high variability of the strength values and the tensile strengths of these fibres are reasonably high. Hence, given the low density and cost of these fibres, they have potential for use as reinforcement materials in cement composites.

Figure 4 shows the variation of flexural strength of different natural fibres in high strength concrete. From the above figure it was observed that the flexural strength increases with increase in all natural fibres dosage compared with conventional concrete. The flexural strength of conventional concrete was 6.5 N/mm^2. The flexural strength of 1.0% sisal and banana fibre was increased by 61.5% and 66.5% respectively than the conventional concrete. Similar findings also proved that the sisal fibre laminates, long sisal fibres were more effective in terms of increasing the flexural and tensile strength and the energy absorption than the conventional laminates [15]. Results from the above Figure shows that there is a slight increase in flexural strength of the high strength concrete (from 6.5 MPa to 8.5 MPa) by addition of 0.5% coir fibre content compared with the control sample. When coir fraction is increased to 1%, a result shows the decreased in flexural strength. This due to difficult to mix homogeneously for concrete has a higher percentage of coconut coir fractions [40].

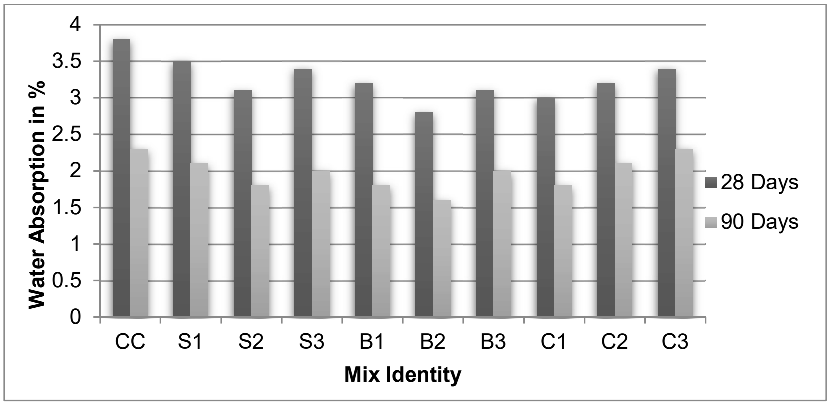

Fig. 5 - Effect of Natural fibre on Water absorption.

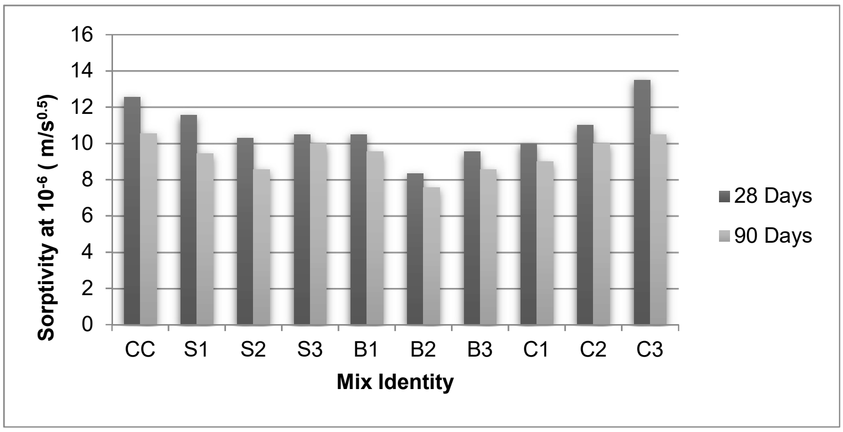

Fig. 6 - Effect of Natural fibre on Sorptivity.

3.3 Effect of natural fibres on water absorption and sorptivity on HSC

The water absorption result shown in Figure 5 given above.

From the results it explains that the water absorption for the control mix was found to be 3.8% and 2.3% at the age of 28 and 90 days respectively. From the results, it was also noted that the addition of Sisal and Banana Fibre in percentage of 0.5 and 1% water absorption value decreases. There is an increase in percentage of water absorption beyond 1% of above mentioned fibre. The highest water absorption capacity in the mix 1% Banana Fibre and was achieving the value of 2.8% and 1.6% at 28 and 90 days respectively. The results indicated that when the fibres arrests the pores present in the concrete and reduces the discontinuous pore structure thereby reducing the capillary pore volume to achieve better particle packing thereby reduce the water absorption. Beyond 1% of sisal and banana fibre the percentage of water absorption was increases. In addition of 0.5% coir fibre the water absorption percentage was 3% and 1.8%, when it was compared to conventional concrete the percentage was reduced by 21% and 23% at 28 and 90 days respectively. And it can be seen that the absorption values at 90 days of all the mixes be lesser than the limit of 3% specified for good concrete. Absorption values for the natural fibres in concrete were found to be the lower than that of conventional concrete. Figure 6 illustrates the influence of natural fibres on the sorptivity of HSC mixes.

Sorptivity value is an important factor to predict the service life of a concrete structure. Increasing the sisal and banana fibre content from 0% to 1%, causes decrease in the sorptivity. In case of sisal fibre the value reduced by 18% and 19.2% at 28 and 90 days respectively and in case of banana fibre the value reduced by 33% and 28.6% at 28 and 90 days respectively. By addition of 0.5% coir fibre, the sorptivity value was 6.06 X 10^{-6}(m/$s^{0.5}$) which was 20% lower than conventional concrete value of 12.56 X 10^{-6}(m/$s^{0.5}$) at 28 days . After 90 days, sorptivity dropped by 20% than the control concrete mix. The natural fibres arrest the capillary pores present in the concrete, so the addition of natural fibre can be beneficial to gain in the strength and reduction in the capillary sorption of concrete.

3.4 Effect of Natural fibres on Chloride ion Penetration on HSC

The ability of concrete to resist chloride ions penetration is an important parameter influencing the durability properties of concrete when it exposed to marine environments. The RCPT values of three different natural fibre mixes at the age of 28 days and 90 days are presented in Figure 7.

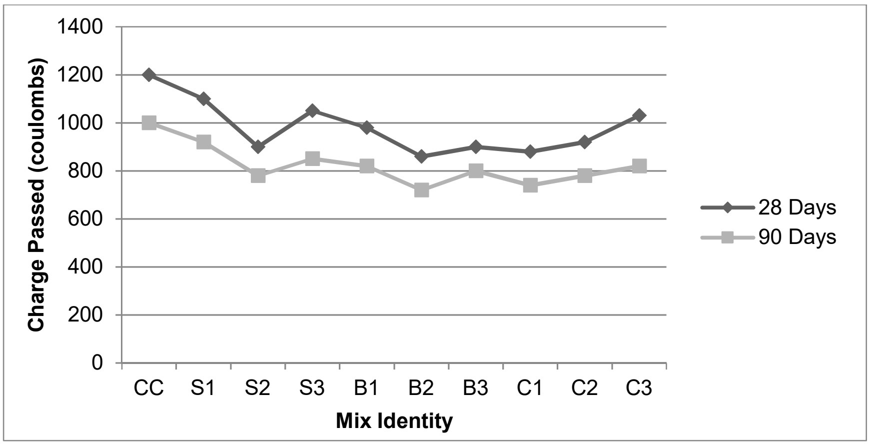

Fig. 7 - Effect of Natural fibre on Chloride ion penetration.

From the results, it was observed that all the mixes have low penetrability to chloride ions. Coulomb value decreased with the increase in 0.5% and 1% sisal and Banana fibre shows that the concrete became denser due to addition of fibre. Beyond 1% of fibre content, a small increase in the coulomb value was noted. Maximum reduction in the coulomb value was observed at 1% in case of sisal and banana and 0.5% in case of coir fibre. By 1% addition of banana fibre shows minimum value of Coulomb value from which it can be found that the concrete exhibit more resistance to chloride ion penetrability than other mixes. The significant reduction in chloride ion penetration may be due to the incorporation of natural fibres which resulted in the improvement of the packing density of the concrete matrix. Coulomb charges passed at 90 days are less than those of 28 days due to the dense microstructure of concrete.

4.Conclusions

Mechanical and durability properties of natural fibre reinforced high strength concrete have been investigated experimentally. The following conclusions can be drawn.

- Results revealed that, the inclusion of natural fibres has increased the strength and durability of high strength concrete.
- Addition of 1% sisal and banana fibre and 0.5% coir fibre resulted in the enhancement of compressive strength, splitting tensile strength and flexural strength of HSC mixes at all ages.
- Water absorption and sorptivity values of HSC reduces with addition of 0.5%, 1% and 1.5% sisal, banana and coir fibre. The maximum reduction in water absorption and sorptivity values was observed in the HSC mixes containing 1% of sisal and banana fibre and 0.5% coir fibre.
- RCPT values of HSC with 1% of sisal and banana fibre and 0.5% coir fibre were very low at both 28 and 90 days. The charges passed in Coulomb in the natural fibre mixes were observed to be lesser than the control mix.
- The increase in strength and durability properties is due to its pore filling effect of natural fibres making the concrete more dense due to improvement in packing density of the concrete mix.

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