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Development and Performance Evaluation of Coir Pith Ash as Supplementary Cementitious Material in Concrete

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Abstract. India is the third largest producer of coconuts in the world after Indonesia and Brazil. The production of coconuts generates enormous volumes of by-products, which are dumped in landfills, causing issues like soil and air contamination, pollution of groundwater and other water bodies, with hazardous impacts on plant and animal life. Coir pith and short fibers are by-products from the coir industry obtained during the extraction of long fibers and account for approximately 70% of the mature coconut husk. Coir pith ash (CPA) was prepared by heating the dried coir pith in a metallic vessel at a temperature of 400 °C for 4 hours. The current paper shows an elaborate technical study on the material properties and performance of CPA in blended cements. The properties of concrete investigated were setting time, workability, compressive strength, splitting tensile strength, flexural strength and ultrasonic pulse velocity values. The specimens were tested at curing ages of 7, 28, 56 and 90 days. The test results indicated that CPA has moderate pozzolanic properties, with 10% as optimum replacement percentage.

Keywords: *supplementary cementitious material; pozzolanic material; agricultural waste; concrete.*

1 Introduction

A wide variety of materials are used in the construction industry and concrete is the most important one among them. Proper design and construction practices can yield concrete with excellent mechanical and durability characteristics. Since the world population and urbanization are showing uncontrolled growth, the concrete production and consumption is also increasing at a remarkable rate, which in turn increases the need for non-renewable raw materials. Cement is the binding material in concrete and its global consumption rate exceeds 4.1 billion tonnes [1]. To produce a single tonne of cement, nearly 4 GJ of energy and 1.7 tonnes of raw materials are needed [2]. These values demonstrate the impact of cement manufacture on the environment and its degradation. Considering this, researchers across the globe have carried out extensive studies to develop and apply supplementary cementitious materials (SCMs) to replace OPC. Several SCMs have shown excellent pozzolanic activity and normally the replacement

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ranges between 10 to 50%. Addition of SCMs improves the quality of concrete by reducing heat of hydration, enhancing chemical resistance, and improving fresh and hardened properties. Industrial by-product based SCMs like fly ash and agricultural by-product based SCMs like rice husk ash have shown excellent pozzolanic properties [3-5]

In the majority of developing and underdeveloped countries, the primary sector is the biggest part of the economy and this dependence leads to the production of large quantities of by-products. Such by-products can be in the form of leaves, roots, peels, hulls, shells, husks, straws, stems, etc, and are usually dumped in landfills, thereby causing issues like soil and air contamination, pollution of groundwater and other water bodies, with hazardous impacts on plant and animal life. To reduce these adverse impacts, developing supplementary cementitious materials from agro-wastes is a promising solution.

2 Coir Industry and Environmental Concern

The world's total production of coconuts is about 61 megatonnes. India is the third largest producer of coconuts after Indonesia and the Philippines. India produces about 11 megatonnes of coconuts every year [6]. The South Indian states of Kerala, Tamilnadu, Karnataka and Andra Pradesh account for 89% of the total coconut production of the country [7], due to which the local coir industry flourishes to a great extent. A typical coconut fruit contains about 35% husk, 12% shell, 28% meat and 25% water [8]. During the processing of husk, the obtained amount of long fibers, which is the main raw material of the coir industry, can be in the range of 30% of the weight of the husks. The remaining 70% comprises short fibers and coir pith [9].

Coir pith is an elastic spongy cellular and light-weight corky material. When 10,000 coconut husks are processed, the average quantity of coir pith obtained is in the range of 1.6 tonnes [10]. As per the findings of Brasileiro *et al.*, coir pith contains a very high amount of lignin (30.7%), cellulose (35.6%) and hemicellulose (33.7%) [11]. The presence of lignin makes natural biological degradation very difficult. Coir pith contains phenolic compounds and it has the capacity to contaminate water bodies if it comes in contact with running water. It is in this context that proper management of coir pith disposal is essential. Currently, a small portion of coir pith is used as a water-retaining medium in agricultural applications. Many researchers across the globe have attempted to incorporate coir pith as a potential additive in concrete and observed its influence on the physical and mechanical characteristics of concrete, such as bulk density, porosity, mechanical strength as well as on thermal properties [11-15]. Brasileiro, *et al.* investigated the effect of coir pith particles in composites with Portland cement and observed that the addition of coir pith improved the ductility and shock absorption capacity of the concrete. However, due to the spongy and porous nature of coir pith, the bulk density and compressive strength of the samples was reduced with coir pith addition [11].

Koňáková, *et al.* worked on the impact of coir pith on the thermal properties of concrete. The thermal insulation capacity was observed to improve by increasing the coir pith dosage. Through all the researches, the optimum dosage percentage of coir pith was concluded to be 5%. The studies also proved that the application of coir pith in concrete would be beneficial from an environmental and economic point of view. It is important to note that the calorific value of coir pith is 3975 kcal per kg, i.e. close to the 4200 kcal per kg of coal [10]. Hence, it has the ability to be considered as a fuel briquette and also for pig iron manufacture. This research was aimed at finding the suitability of ash derived from coir pith as supplementary cementitious material for concrete.

3 Material Charecteristics

3.1 Coir Pith Ash (CPA)

Coir pith was collected from a coir fiber mill located in Chingoli, a village situated in the coastal area of the Alappuzha district of Kerala, India. To prepare the coir pith ash, the raw coir pith was dried in sunlight for 24 hours to reduce its moisture content. Then the dried coir pith was heated in a metallic vessel at a temperature of 400 °C for 4 hours. The temperature was monitored using a digital non-contact infrared thermometer. The obtained ash was allowed to cool for 6 hours. After cooling, the ash was sieved through a 200-micron sieve and then collected and stored in an airtight container**.** The color of the ash obtained was grey, see Figure 2.

Figure 1 Coir pith.

Figure 2 Coir pith ash.

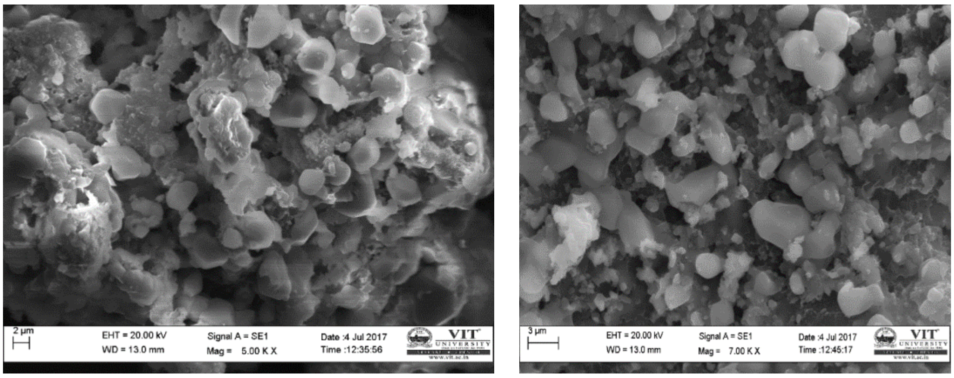
The specific gravity of the ash sample was calculated and found to be 2.2. Chemical analysis of the CPA was carried out using a Perkin Elmer Pinnacle

900 F (USA 2016). The main components of CPA were found to be silica and KCl. The results of the chemical analysis are shown in Table 1. The other main components include, i.e. CaO, Al_2O_3, Fe_2O_3, MgO, and SO_3. LOI was just below 10%.

Table 1 Chemical composition of CPA.

Sl.No	Composition	OPC (%) [16]	CPA (%)
1	CaO	60-67	16.14
2	SiO_2	17-25	34.50
3	Al_2O_3	3.0-8.0	01.35
4	Fe_2O_3	0.5-6.0	02.22
5	MgO	0.1-4.0	02.07
6	SO_3	1.3-3.0	-
7	KCl	-	26.48
8	LOI	-	09.43

A scanning electron microscope (ZEISS EVO18) was used to carry out a microstructural analysis of the CPA sample. The microstructure is important because it can have a great impact on the fresh and hardened properties of the concrete. The SEM observation showed a regular morphology, containing relatively spherical shaped particles of SiO_2. The SEM images are shown in Figures 3(a) and (b).



(a) SEM analysis of CPA (b) SEM analysis of CPA

Figure 3 SEM images.

3.2 Aggregates

The fine aggregate and coarse aggregate used in this research were locally available. Natural silica river sand passing through 4.75-mm IS sieve was used as fine aggregate. Aggregate passing through a 20-mm IS sieve but retained on a 10 mm IS sieve was used as coarse aggregate. The coarse aggregate was properly washed prior to fresh concrete preparation and were used in saturated surface dry condition. A number of aggregate characteristics were determined, i.e. specific gravity, water absorption and fineness modulus. The results are shown in Table 2. A detailed sieve analysis was also conducted; the sand used as fine aggregate conformed to Zone II classification.

Table 2 Aggregate characteristics.

Sl No	Characteristics	Fine aggregate	Coarse aggregate
1	Specific gravity	2.67	2.70
2	Water absorption (%)	1.39	0.81
3	Fineness modulus	3.53	7.22

3.3 Cement

The cement used in this research was 53 grade ordinary Portland cement (OPC) manufactured by Ultratech Cements, satisfying the requirements as per IS 12269: 2013 [17]. Various cement characteristics were determined, i.e. fineness, specific gravity, normal consistency and setting times. A summary of the characteristics of the cement used in the experiment is listed in Table 3.

Table 3 Cement characteristics.

Sl No	Characteristics	Values
1	Grade	53
2	Fineness	8%
3	Specific gravity	3.15
4	Normal consistency	36.75%
5	Initial setting time	77 minutes
6	Final setting time	320 minutes

4 Methodology

4.1 Mix Design

The mix design for M25 grade concrete was carried our as per IS 10262: 2009 [18]. The obtained mix proportion was 1: 1.5: 2.58 and the water–cement ratio applied was 0.49. A total number of 5 proportions, including a control mix and four mixes containing CPA, were considered. The cement replacement percentage varied from 5% to 20%. The mix proportions and material quantity required per m^3 of concrete are shown in Table 4. A total number of 120 cubes, 60 cylinders and 30 beam specimens were prepared.

Notations for mix proportions:

1. CM – Control Mix
2. P05 – 5% cement replaced by CPA
3. P10 – 10% cement replaced by CPA
4. P15 – 15% cement replaced by CPA
5. P20 – 20% cement replaced by CPA

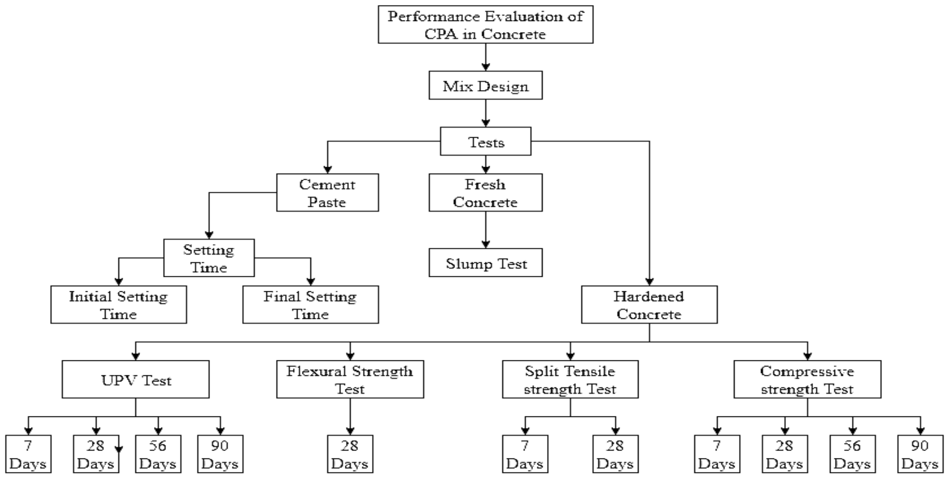


Figure 4 Methodology flow chart.

Table 4 Proportions of various mixes.

Mixture No	CPA (%)	CPA (Kg)	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Ltr)
CM	0%	0	438.13	655.72	1130.29	215.49
P05	5%	21.92	416.23	655.72	1130.29	215.49
P10	10%	43.81	394.32	655.72	1130.29	215.49
P15	15%	65.72	372.41	655.72	1130.29	215.49
P20	20%	87.63	350.51	655.72	1130.29	215.49

4.2 Initial and Final Setting Time Tests

The term ‘setting’ refers to the stiffening of the cement paste. The main mechanism behind setting is the hydration of C_3A and C_3S, and it is generally accompanied by a temperature rise. The tests for initial and final setting times for various mixes were carried out as per IS: 4031 (Part 5) – 1988 [19]. The variation of initial and final setting times with increase in the replacement percentage of cement by CPA were studied. The specifications were obtained from IS: 4031 (Part 5) – 1988 [19].

4.3 Slump Test

As per IS 1199: 1959 workability is defined as: “The property of concrete which determines the amount of useful internal work necessary to produce complete compaction” [20]. In other words, workability is the ease with which concrete can be mixed, transported, molded and compacted. A slump test is an empirical test to measure the workability of fresh concrete and was carried out to check the variation of workability with addition of CPA to the concrete. The test was carried out as per IS 1199: 1959. [20]

4.4 Compressive Strength

Compressive strength is considered one of the most significant properties of concrete and a main indicator in quality control. The main parameters that influence concrete strength are material type, material quality, mix proportions, curing conditions and method of testing. The microstructural aspects, porosity and extent of hydration also play a crucial role. In order to find the compressive strength of hardened concrete, cube specimens of size 100 x 100 x 100 mm were prepared as per IS 516: 1959[21]. After casting, the specimens were kept at 27 ± 5 °C for 24 hours and were then subjected to water curing. The specimens were tested on day 7, 28, 56 and 90 using a compression testing machine with a maximum capacity of 2000 KN. The pace rate was set to 2.3 KN/s according to IS 516: 1959 [21]. The method of curing used was water curing and the concrete was tested in wet condition.

4.5 Split Tensile Strength

The split tensile strength of concrete was measured as per IS 5816: 1999 [22]. After casting, cylindrical specimens of size 100 mm diameter and 200 mm height were kept at 27 ± 5 °C for 24 hours and then subjected to water curing. The specimens were tested on day 7, 28 and 90.

4.6 Flexural Strength Test

The flexural strength of concrete refers to the resistance offered against bending. A flexural strength test was carried out as per IS 516: 1959 on simply supported unreinforced simple concrete beams of dimension 100 x 100 x 500 mm on day 28 [21]. In order to conduct the test, the third point loading method was used and the modulus of rupture value was found. The specimen was loaded until failure and the peak load at failure was noted.

4.7 Ultra Sonic Pulse Velocity Method

The ultrasonic pulse velocity (UPV) method is a prominent non-destructive testing method used to evaluate the uniformity and relative quality of existing concrete specimens and structures. Usually, a high pulse velocity reading indicates better quality of the concrete. The specimens were subjected to a UPV test as per IS 13311 (Part 1): 1992 [23]. The tests were conducted on day 7, 28, 56 and 90. Table 5 shows the grading of the concrete as per IS 13311 (Part 1): 1992 [23].

Table 5 Grading of concrete based on UPV.

Pulse Velocity	Concrete Quality Grading
Above 4.5 Km/S	Excellent
3.5- 4.5 Km/S	Good
3.0-3.5 Km/S	Medium
Below 3.0 Km/S	Doubtful

5 Results and Discussions

5.1 Initial and Final Setting Time

The results of the initial and final setting time tests of the CPA blended cement paste are shown in Table 6. The initial setting time was observed to range from 77 minutes with 0% CPA blended cement paste to 216 minutes with 20% CPA blended cement paste. Due to the reduced amount of cement, the C_3S and C_3A content decreases, which slows down the hydration process and in turn results in a marginal delay in the initial setting. However, only a slight delay was observed in the final setting time. The final setting time ranged from 320 to 444 minutes as the CPA content increased from 0% to 20%.

Table 6 Initial and final setting time.

Percentage Replacement	Initial Setting Time (Min)	Final Setting Time (Min)
0	77	320
5	89	335
10	114	357
15	155	392
20	216	444

5.2 Slump Test

A slump test was carried out to evaluate the impact of CPA on the workability of the concrete. The results are shown in Table 7. From the results it can clearly be seen that the workability increased with an increase in the percentage of CPA addition. The slump value of CM and P20 were 103 mm and 130 mm respectively. Thus, the increase in slump was nearly 25%. The SEM analysis revealed a spherical shape of the CPA particles, which could be the reason for the increase in slump.

Table 7 Slump values for CPA blended cement concrete.

Concrete Mix	Slump Value (mm)
CM	103.00
P05	110.00
P10	115.00
P15	124.00
P20	130.00

5.3 Compressive Strength Test

The result of the compressive strength test of the CPA blended concrete is shown in Table 8. It can be seen that the compressive strength increased with an increase in curing period. Mix P05 showed better strength than the control mix at all curing periods. The compressive strength of CM and P05 at 90 days was 34.31 MPa and 36.95 MPa respectively. The test results also revealed that the rate of pozzolanic action was very low during the initial curing period. At 90 days curing, however, the pozzolanic action was well observed, especially in the P05 mix. Thus, the effect of CPA addition was more significant during prolonged curing periods. The compressive strength decreased as the replacement percentage increased beyond 5%. The main reason for the decrease in strength is the reduction in cement content, which is the binding material in concrete, and the slower rate of the pozzolanic reaction. From the results it can be concluded that CPA can act as a pozzolanic material. However, when compared with other pozzolanic materials derived from agricultural wastes, such as rice husk ash and sugarcane bagasse ash, CPA shows less pozzolanic activity since the optimum replacement dosage of both sugarcane bagasse ash and rice husk ash in concrete was found to be 20% in previous investigations by various researchers [3-5,24-26].

Table 8 Compressive strength of CPA concrete.

Mix	Strength (MPa)			
	7 Days	28 Days	56 Days	90 Days
CM	28.76	31.03	33.88	34.31
P05	28.96	32.13	35.29	36.95
P10	24.67	27.60	29.14	29.70
P15	20.23	24.33	25.13	26.01
P20	14.20	15.87	18.80	18.87

As per ASTM C 618 – 08, for an SCM to be considered as pozzolanic material, the strength of the blended cement at curing periods of 7 days and 28 days should not be less than 75% of the strength of the control mix [27]. From Table 8 it is clear that after 7 days of curing the strength of P05 and P10 was more than 75% of the strength of CM. After 28 days of curing, the strength of P05, P10 and P15 was more than 75% of the strength of CM. Thus the minimum permissible limits were satisfied by P05 and P10 at 7 days and by P05, P10 and P15 at 28 days.

5.4 Split Tensile Strength

The splitting tensile strength result for the CPA blended concrete is shown in Table 9. Similar to compressive strength, splitting tensile strength also increased with an increase in curing duration. Mix P05 showed better performance than CM after 28 days and 90 days. An increase in CPA percentage beyond 5% lowered the split tensile strength due to reduced cement content and slower rate of the pozzolanic reaction. Thus, 5% CPA can be considered the optimum replacement percentage.

Table 9 Split tensile strength of CPA blended concrete specimens.

MIX	Strength (MPa)	
	28 Days	**90 Days**
CM	2.45	2.74
P05	2.52	2.97
P10	2.29	2.41
P15	2.04	2.20
P20	1.86	1.95

5.5 Flexural Strength

The results of flexural testing on concrete beams are shown in Table 10. The flexural strength test of the concrete specimens showed that P05 performed better under flexure than the control mix after 28 days of curing. The resistance to flexure declined as the replacement percentage increased beyond 5%. The strength of the CM and P05 mixes at 28 days of curing were 7.40 MPa and 7.60 MPa respectively.

Table 10 Flexural strength of CPA blended concrete specimens.

MIX	Flexural Strength (MPa) 28 Days
CM	7.47
P05	7.60
P10	7.07
P15	5.47
P20	4.60

5.6 Ultra Sonic Pulse Velocity Testing

The ultrasonic pulse velocity values represent the homogeneity and the variation in quality of the concrete over a curing period. Generally, the UPV values increased with an increase in curing period for all mixes. The results of the tests carried out on day 7, 28 and 56 show that an increase in CPA content reduced the UPV values. However, after 90 days a very slight increase in the UPV values was shown by P05 when compared to CM. The pozzolanic reaction of the CPV produces more CSH gels and this increases the density of the concrete by filling the pores, which consequently increases the UPV values. The values decreased again while testing the P10, P15 and P20 mixes. This was due to the lower specific gravity of the CPA and the reduced cement content in the concrete mass.

Table 11 UPV of CPA concrete at various curing periods.

Sl No	Mix	UPV VALUES (m/s)			
		7 Days	28 Days	56 Days	90 Days
1	CM	4657	4955	5027	5129
2	P05	4458	4753	4990	5152
3	P10	4197	4457	4885	5030
4	P15	3968	4332	4810	4911
5	P20	3622	4187	4742	4803

6 Conclusion

The study was aimed at exploring the effectiveness of coir pith ash (CPA) as a supplementary cementitious material. From the experiment results, the following conclusions can be drawn. A microstructural analysis was carried out on the CPA, which revealed a regular morphology and the presence of relatively spherical shaped particles. The initial and final setting time increased with an increase in CPA content in the cement paste.

The impact of the CPA on the workability was assessed using a slump test. The slump improved with an increase in CPA content. An increase of up to 25% was observed for a maximum of 20% replacement. The impact of the CPA on the mechanical properties was evaluated by carrying out a compressive strength test, a splitting tensile strength test and a flexural test. The compressive strength, the splitting tensile strength and the flexural strength improved when 5% CPA replacement was adopted. However, a further increase to 20% CPA replacement reduced the desirable properties. Also, the mix with 10% replacement satisfied the minimum permissible limits for compressive strength as per ASTM C618 – 08.

After 90 days, 5% replacement of cement with CPA showed improved UPV compared to that of the control mix. At all other curing periods less than 90 days, the UPV decreased with an increase in CPA content. However, for 56 days and 90 days of curing, all mixes showed values greater than 4500 m/s, which confirmed the excellent quality and integrity of the CPA concrete. From the results it can be concluded that CPA can act as a pozzolanic material and the optimum percentage of cement replacement by CPA was concluded to be 10%. However, when compared with other pozzolanic materials derived from agricultural wastes, such as rice husk ash and sugarcane bagasse ash, CPA shows less pozzolanic activity.

References

[1] US Geological Survey, *Mineral Commodity Summaries*, 2018. https://minerals.usgs.gov/minerals/pubs/mcs/2018/mcs2018.pdf (31 March 2018)

[2] Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A.N. & Mirza, J., *Reduction in Environmental Problems Using Rice-husk Ash in Concrete*, Construction and Building Materials, **30**, pp. 360-365, 2012.

[3] Hwang, C.L., Tuan, B.L.A. & Chen, C.-T., *Effect of Rice Husk Ash on the Strength and Durability Characteristics of Concrete*, Construction and Building Materials, **25**(9), pp. 3768-3772, 2011.

[4] Alex, Josephin, J. Dhanalakshmi & Ambedkar, B., *Experimental Investigation on Rice Husk Ash as Cement Replacement on Concrete Production*, Construction and Building Materials, **127**, pp. 353-362, 2016.

[5] Madandoust, R., Ranjbar, M.M., Moghadam, H.A. & Mousavi, S.Y., *Mechanical Properties and Durability Assessment of Rice Husk Ash Concrete*, Biosystems Engineering, **110**(2), pp. 144-152, 2011.

[6] FAO, *FAO Statistical Yearbook 2014,* Food and Agriculture Organization of the United Nations, 2014.

[7] Reghuvaran, A., & Ravindranath, A.D., *Process Improvement of Coir Pith Degradation Involving White Rot Fungi By Substitution of Urea With Nitrogen Fixing Bacteria and Application of Biodegraded Coir Pith as Plant Growth Medium.* PhD diss., Cochin University of Science and Technology, 2013.

[8] Thampan, P.K. *Hand Book on Coconut Palm*, Oxford and IBH Publishing Co., New Delhi, 15, pp. 260-274, 1991.

[9] Fontenele, R.E.S., *Coconut Culture in Brazil: Current Market Characterization and Future Prospects,* In: XLIII Congress of Sober. Ribeirão Preto, SP, Brasil, , 2005. Available from: http://www.sober.org.br/palestra/2/168.pdf (accessed 10 January 2013)

[10] Ravindranath, D.A. & Radhakrishnan, S., *Coir Pith -Wealth from Waste - A Reference*, Published on the Occasion of the India International Coir Fair 2016, Coimbatore, Coir Board, (Ministry of Micro, Small & Medium Enterprises, Govt. of India), 2016.
[11] Brasileiro, G.A.M., Vieira, J.A.R. & Barreto, L.S., *Use of Coir Pith Particles in Composites with Portland Cement,* Journal of Environmental Management, **131**, pp. 228-238, 2013.
[12] Koňáková, D., Vejmelková, E., Čáchová, M., Siddique, J.A, Polozhiy, K., Reiterman, P., Keppert, M. & Černý, R., *Treated Coconut Coir Pith as Component of Cementitious Materials*, Advances in Materials Science and Engineering, **2015**, Article ID 264746, 8 pages, 2015.
[13] Raveendran, G. & James, S.C., *Strength Characteristics of Cement-Coir Pith Composite and Cement-Coir Pith-Glass Powder Composite: Soft ground Arresting System*, International Research Journal of Engineering and Technology (IRJET), **4**(4), pp. 1779-1783, 2017.
[14] Sangeetha, M., Nivetha, V., Jothish, S., Gopal, R.M. & Sarathivelan, T., *An Experimental Investigation on Energy Efficient Lightweight Light Translucent Concrete*, Int. J. Sci. Res. Dev., **3**(2), pp. 127-130, 2015.
[15] Vejmelková, E., Koňáková, D., Krojidlová, A., Hovorková, V., Čáchová, M., Reiterman, P., & Černý, *Properties of Cement Composites Containing Coir Pith,* Advanced Materials Research, **982**, pp. 136-140, 2014.
[16] Shetty, M.S., *Concrete Technology: Theory and Practice,* S. Chand & Company LTD, New Delhi, India, 2005.
[17] Bureau of Indian Standards, *53 Grade Ordinary Portland Cement*, IS 12269: 2013, New Delhi, 2013.
[18] Bureau of Indian Standards, *Guidelines for Concrete Mix Design Proportioning*, IS 10262:2009, New Delhi, 2009.
[19] Bureau of Indian Standards, *Methods of Physical Tests for Hydraulic Cement, Part 5: Determination of Initial and Final Setting Times*, IS: 4031 (Part 5) – 1988, New Delhi, 1988.
[20] Bureau of Indian Standards, *Methods of Sampling and Analysis of Concrete*, IS 1199:1959, New Delhi, 1959.
[21] Bureau of Indian Standards*, Method of Tests for Strength of Concrete*, IS 516: 1959, New Delhi, 1959.
[22] Bureau of Indian Standards, *Splitting Tensile Strength of Concrete - Method of Test,* IS 5816: 1999, New Delhi, 1999.
[23] Bureau of Indian Standards, *Non-destructive Testing of Concrete – Methods of Test, Part 1: Ultrasonic Pulse Velocity,* IS13311 (Part 1), New Delhi, 1999-28,1992.
[24] Amin, N., *Use of Bagasse Ash in Concrete and its Impact on the Strength and Chloride Resistivity*, Journal of Materials in Civil Engineering, **23**(5), pp. 717-720, 2010.

[25] Chusilp, N., Jaturapitakkul, C. & Kiattikomol, K., *Utilization of Bagasse Ash as a Pozzolanic Material in Concrete*, Construction and Building Materials, **23**(11), pp. 3352-3358, 2009.
[26] Ganesan, K., Rajagopal, K. & Thangavel, K., *Evaluation of Bagasse Ash as Supplementary Cementitious Material*, Cement and Concrete Composites, **29**(6), pp. 515-524, 2007.
[27] ASTM C618-08, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, ASTM International, West Conshohocken, PA, 2008, www.astm.org