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The Performance of the Low Cost Masonry Cement Blocks as a Partial Substitution of Coconut Shell Ash

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Abstract: Aim of the research was to investigate the effect of Coconut Shell Ash (CSA) with cement as a partial substitution in the production of alternative cement blocks to subsist conventional ones. Utilization of this natural agro waste material helps to prevent the environmental pollution, reduces the construction cost as well as contributes to sustainable construction. Therefore, 90 blocks of 450 mm × 150 mm × 225 mm masonry cement blocks of mixing value 1:6 were cast, cured and tested after 7, 21 and 28 days. CSA was substituted at 0 to 50 wt.% at 5% intervals. The materials were mixed well with the addition of sufficient water. The maximum compressive strength and flexural strength of 300 kg/cm^2 and 12.52 kg/cm^2 were recorded at 5% supersession at the 28^{th} day, respectively, which is found congruous and recommended for building construction having procured a 28^{th} day compressive strength of more than 280 kg/cm^2 as required by the Sri Lankan Standards. The compressive and flexural strengths of the cement / CSA blocks generally decrease as the percentage of CSA content increases. However the dry density, water absorption, compressive strength and flexural strength results conclude that the 10% CSA addition is the optimal value for the production of environmental friendly low cost alternative cement blocks.

Keywords: Coconut Shell Ash, Cement Block, Alternative Building Material, Water Absorption, Compressive Strength, Flexural Strength, Sustainable Construction, Amorphous Silica

1. Introduction

Concrete blocks (CBs) are composed of cement, sand and dihydrogen monoxide, moulded into different volumes. It is used all over the Sri Lanka and some other countries. The class of CBs manufactured however, changes from place-to-place and industry-to-industry due to different technologies employed in the manufacture and the properties of the principal materials.

The paramountcy of the CBs as a component of local building materials cannot be over accentuated in the construction industry. CBs have been commonly utilized for a building structure in Sri Lanka. The rapid transmutations in the utilization of brick-to-block in Sri Lanka have emboldened the research into the utilization of CBs to be more elaborate.

In Sri Lanka, the costs of manufacturing of concrete blocks have been gradually incremented owing to the cost of cement. This will persuade manufacturers to engender blocks with a low cement content which leads to micro cracks on the walls after construction. It is disappointing to note that most of the country bricks fail to satiate the strength criterion and have high water absorption. The utilization of alternative waste materials as stabilizers will significantly improve the engenderment of CBs with the desired properties at low cost [1]. It will withal extremely decrease the cost of engenderment and subsequently the cost of construction works. Rice Husk Ash is an agro waste material which can be utilized as a supersession of cement without sacrificing the strength and durability.

This, coupled with the pollutants associated with cement production, has necessitated a look for an opportunity binder which can be used sorely or in a partial substitute of cement in the concrete block manufacturing. Greater so, disposal of agro waste substances together with rice husk, groundnut husk, corn cob and coconut shell have constituted an environmental assignment, as a result the need to transform them into beneficial materials to decrease their poor impact on the surroundings [2]. Studies indicate that most materials which are rich in amorphous silica can be used in a partial alternative of cement [3, 4-6]. It has also been installed that amorphous silica found in few pozzolanic materials reacts with lime greater without difficulty than_ones of crystalline form [7]. Use of such pozzolans can lead to expanded compressive and flexural strengths [8-9]. The American society of testing materials (ASTM) defines pozzolans as siliceous or aluminous materials which possess little or no cementitious homes but will, within the presence of moisture, react with lime [Ca(OH)2] at normal temperature to form a compound with pozzolanic residences. Examples of pozzolans encompass class C fly ash, which contain extra than 10% CaO, blast furnace slag and silica fumes [10]. ASTM C 618 – 78 specifies that any pozzolana a good way to be used as a cement binder in concrete requires for at least 70% silica, alumina and ferric oxides. BS 3892: 1965 parts 1 and a couple of specify a maximum loss on ignition of 12%, maximum MgO content material of 4% and SO3 of 2.5%, respectively [11-12].

Coconut is grown in more than 90 countries. Where in, Sri Lanka is the fifth biggest, having cultivation of about 2,513,000 metric tons of coconut per year [13]. However, it is also the main contributor to the country's pollution problem as a stable waste within the form of shells. This waste may be applied as an alternative for either pleasant or coarse combination or cement in concrete manufacturing.

Coconut shells as a combination concrete received the use of coconut shell as a rough mixture satisfies the minimal requirements for concrete. Coconut shell combination led to applicable energy that's required for structural concrete. Coconut shell may also gift itself as a capacity fabric within the field of production industries. The coconut shell is like minded with cement and no want to pre-treatment for using it as coarse mixture. Because of the clean surface on one side of the shells concrete made with coconut shell offers better workability. Coconut shell concrete suggests accurate effect resistance. Compared to standard aggregate water soaking up and moisture preserving capability of coconut shell is excessive. The presence of sugar within the coconut shell, does no longer affect the setting and power of concrete as it isn't in an unfastened shape. It is discovered that wooden primarily based substances being tough and of natural origin, will not contaminate or leach to supply toxic substances once they're certain in concrete matrix [14-16].

Coconut shells ash as cement research suggests that maximum materials which are in rich may be utilized in a partial alternative of cement. It has also been established that amorphous silica determined in some pozzolanic substances which react with lime extra effortlessly than the ones of crystalline form [3-6]. Use of such pozzolana can cause growth in compressive and flexural strengths [8-9]. The raw materials used for the producing of cement consist mainly of lime, silica, alumina, and iron oxide. Normally, the chemical analysis of coconut shell ash well-known shows that it contains some portions of those elements [1]. As a result, coconut shells ash may be used correctly as a supplementary cementitious cloth.

The aim of this work is to find good value and environmental helpful answer for excessive fee of concrete and to research the use of coconut shell as a coarse mixture in concrete and look into the strengths of coconut shell concretes at distinct coconuts shells (CS) replacements and also to have a look at the effect on strength of partially replaced concrete via adding plasticizers. On this paper, the effect of coconut shells ash as an alternative of cement in concrete is investigated. the purpose of this examine is to determine the suitability of coconut shell ash (CSA) to be used in partial substitute of cement in concrete production and also have a look at the impact on strength of partially replaced concrete via adding plasticizers.

2. Experimental Methodology

2.1. Materials

2.1.1. Sand

Sand is a normally happening granular material which is an essential fine total has predominant bond of parts in concrete. It gives quality by filling in as little fillers in a blend. Cement binds sand particles together forming one solid sand mix. River sand that used in this study was liberate from clay, loam, dirt and organic matter of any description. Before using, it was cleaned and sand size analyzed were done in accordance with the Sri Lankan Standards SLS 882:1989 [17] using 425 μm sieves. The sand had a categorical gravity of 2.60.

2.1.2. Cement

Pozzolona Portland cement is used in this work, which is a main binding material as per the Sri Lankan standards SLS 107: Part 1: 2008 [17], most commonly used in construction works. The chemical composition of the cement is tabulated in Table 1 [1].

Table 1. *The chemical compositions of the Pozzolona Portland cement.*

Oxide compositions	J. T. Utsev and J. K. Taku [1]
SiO_2	20.70
Al_2O_3	5.75
Fe_2O_3	2.50
CaO	64.00
MgO	1.00
MnO	0.20
Na_2O	0.60
K_2O	0.15
ZnO	-
P_2O_5	0.05
SO_3	2.75
LOI	2.30

2.1.3. Water

Fresh water was used to mix the materials, which was free from organic matters of any type as described in Sri Lankan Standards 522: Part 1:1989 [17]. It activates the chemical reaction in the cement and with other materials and forms cement gel.

2.1.4. Coconut Shell Ash (CSA)

The coconut shells were acquired from kitchen waste sell off in Batticaloa, Eastern Region, Sri Lanka. They were finally spread on matting and allowed to properly dry to facilitate right combustion at some points of burning. This material changed into burnt and into ashes in a furnace at a temperature range of 500 to 550°C for two hours to provide the coconut is discovered that the liquid restrict is minimal, while CSA delivered is 4%, the plastic restriction increases with boom in% CSA content however the variant is marginal. Then, the ash was allowed to cool and kept in an air tide container. The oxide compositions were investigated and tabulated in Table 2 and compared with the previous studies.

Table 2. *The oxide compositions of Coconut Shell Ash (CSA).*

Oxide compositions	Present study	B. W. Isah [19]	J. T. Utsev and J. K. Taku [1]
SiO_2	43.5	44.05	37.97
Al_2O_3	15.2	14.60	24.12
Fe_2O_3	12.6	12.40	15.48
CaO	3.25	4.57	4.98
MgO	15.01	14.20	1.89
MnO	0.19	0.22	0.81
Na_2O	0.47	0.45	0.95
K_2O	0.49	0.52	0.83
ZnO	0.5	0.30	-
P_2O_5	0.4	-	0.32
SO_3	-	-	0.71
LOI	8.39	8.69	11.94

2.2. Manufacture of Concrete Blocks

The cement-CSA concrete blocks were cast in 450 mm × 150 mm × 225 mm dimension and its optimum mix ratio of 1:6. The blocks were cast in different ratio, was varied in 6 steps of 10% to a maximum of 60%. For each mixing levels, 3 blocks were cast. Hand mixing was employed, and the materials were turned over a number of times until an even colour and consistency were procured. Water was integrated as required, and the materials were further turned over to secure adhesion. It was then placed into the mould, compacted and smoothened off with a steel face implement. After removing form the mould, blocks were laid and left to dry for 2 days under direct sunlight. Each block was allowed to cure for 7, 21 and 28 days. This is because to find out the correct curing time which uses to obtain the stress measurement from a hydraulic press machine for compressive strength tests. Particle size, water absorption and compressive strength measurements were taken to analyze the new product.

3. Analyzes of Brick Properties

Particle size, Compressive strength and water absorption were analyzed and the results of these properties were compared with the Sri Lankan and British Standards.

3.1. Particle Size Analysis

The particle size analyses were performed for sand and CSA. Majority of the fine CSA and sand particles passed through 425 μm and 455 μm British Standard test sieves, respectively.

3.2. Water Absorption (WA) Analysis

The water absorption property was analyzed as per SLS 855: Part 2: 1989 [17]. This should be in the limit of 12 to 20% as per the BS 5628: Part 1:2005 [18]. This property is not a requirement as indicated in SLS 855: Part 1: 1989 [17]. However, it is a useful unique property to determine some other parameters. Water absorption property of the blocks was analyzed for three bricks in each set. Initially, bricks were kept under the sunlight of temperature of 35°C to 40°C for one day and the dry weights were measured. These bricks were immersed in the water for one day and the wet weight was measured. Water absorption is presented as a percentage was calculated using the below equation, and the average value was calculated for each set of blocks.

$$WA = [(M_{WW} - M_{DW}) / M_{DW}] \times 100\% \quad (1)$$

Where M_{DW} – mass of the dry block and M_{WW} – mass of the wet block after 24 hours.

3.3. Compressive Strength (CS) Analysis

Compressive strength analyses were done using Universal Testing Machine available in the Department of Physics, Eastern University, Sri Lanka. The testing procedure was performed according to the Sri Lankan Standards 855: Part 1: 1989 [17], which is similar to ASTM C67-05. The maximum force applied to break the block, with and length of the block was recorded. Three blocks from each set were measured and the average compressive strength was determined, compared with the Sri Lankan standards.

$$CS = \text{Applied force at the peak / Area of the block} \quad (2)$$

3.4. Flexural Strength (FS) Analysis

Three point twisting test was done according to the Sri Lankan Principles 855: Part 1: 1989 [17] to decide the flexural quality of the block which is like the ASTM D1365-05 standard. The setup of the block for the estimation is appeared in the Figure 3. The braking power and the width of the block were recorded to decide the flexural quality (FQ).

$$MR = FL / wh^2 = 3Fa / 2wh^2 \quad (3)$$

Where MR is flexural strength, (kPa), L is span length, (mm), w and h are width and height of the block, (mm) respectively, a is distance between line of fracture and the nearest support, (mm), and F is maximum applied load (kN).

4. Results and Discussion

The results are presented in tabular and graphical forms for density, water absorption, compressive and flexural strengths as a function of percentage CSA content at ages 7, 21 and 28 days. Table 3 shows the summarized details of the properties of the cement-CSA blocks. Table 1 and 2 shows the chemical oxide composition of the OPC and CSA, respectively. Table 2 indicates that CSA contains 43.5% SiO_2, 15.2% Al_2O_3 and 12.6% Fe_2O_3. This contributes 71.3% (SiO_2+Al_2O_3+Fe_2O_3) of compound oxide that satisfy the minimum requirement of 70% pozzolana which is in line with ASTM C 618-78 requirement [1]. Furthermore, the LOI of 8.31 lies within agreeable limit.

Table 3. *The summarized details of the properties of the cement-CSA blocks.*

Cement: CSA%	Average Density			Average Water Absorption%			Average Compressive Strength			Average Flexural Strength		
	7 days	21 days	28 days	7 days	21 days	28 days	7 days	21 days	28 days	7 days	21 days	28 days
100:0	2000.00	1983.20	1943.90	7.10	8.30	11.30	240.00	280.00	320.00	10.84	11.71	12.52
95:05	1992.50	1968.20	1943.00	7.70	9.70	11.90	220.00	250.00	300.00	10.38	11.07	12.12
90:10	1989.40	1948.60	1912.70	8.10	10.30	12.30	173.00	199.00	290.00	9.21	9.87	11.92
85:15	1975.50	1935.10	1890.20	8.50	10.30	12.80	159.00	172.00	190.00	8.83	9.180	9.65
80:20	1962.90	1920.70	1865.70	9.10	10.52	13.30	93.00	153.00	167.00	6.75	8.66	9.05
75:25	1949.90	1918.30	1860.30	9.00	11.10	13.50	85.00	120.00	158.00	6.45	7.67	8.795
70:30	1896.60	1871.00	1854.90	8.80	11.80	14.00	67.00	98.00	143.00	5.73	6.93	8.375
65:35	1854.00	1824.00	1818.00	10.30	13.50	14.30	51.00	82.00	112.00	4.99	6.34	7.41
60:40	1789.30	1750.80	1742.10	13.40	16.00	14.20	33.00	67.00	103.00	4.02	5.73	7.10
55:45	1730.60	1708.50	1700.50	14.20	16.50	15.00	30.00	65.00	100.00	3.83	5.64	7.00
50:50	1689.30	1679.00	1684.00	15.20	15.60	15.20	30.00	66.00	98.000	3.83	5.69	6.93

4.1. Setting Time

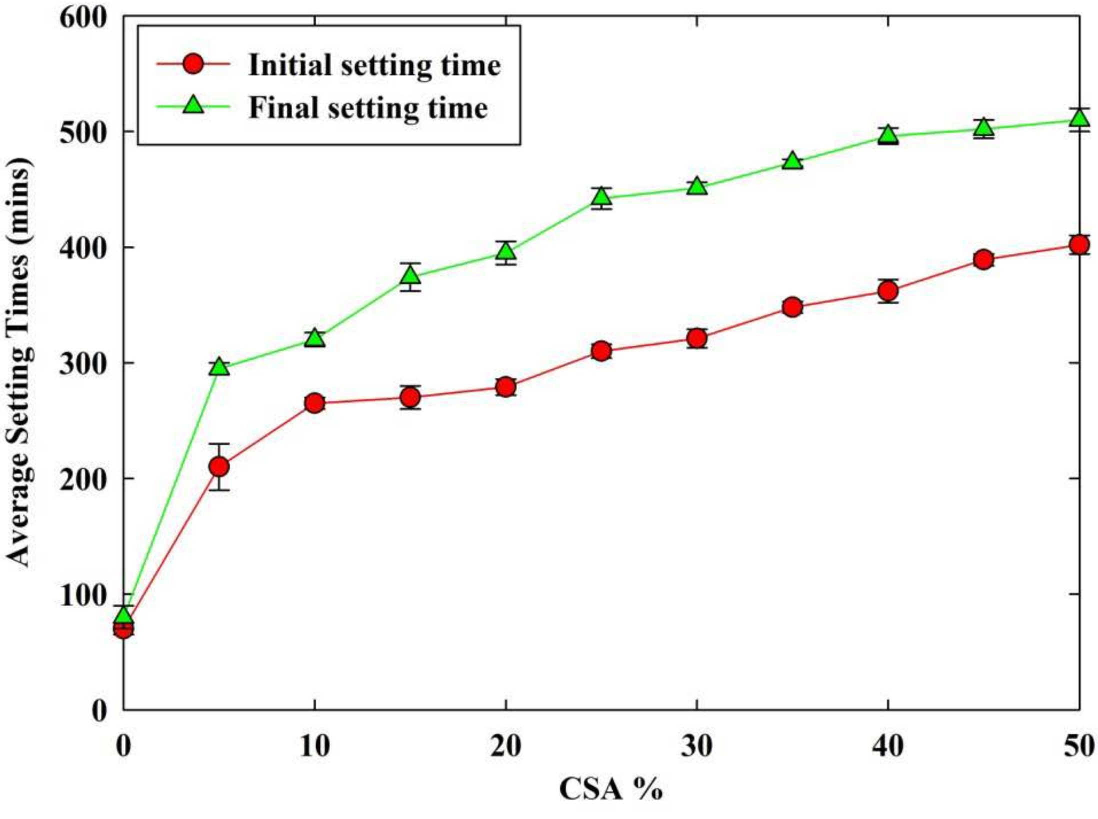

Figure 1. *The average setting time as a function of CSA doping percentage. Red solid circle (●) with the solid line represents the initial setting time and the green solid upper triangle (▲) with the solid line represents the final setting time.*

Initial and final setting times as a function of CSA doping percentage are shown in Figure 1. The setting times increase with the increase in the doping percentage of CSA. The initial setting time increases from 1 hour 10 minutes for pure block to 6 hours 7 minutes at 50% doping, while the final setting time increases from 1 hour 20 minutes for pure block to 8 hours 5 minutes at 50% doping. However, according to the BS12 (1978) [1] recommends initial setting time should be less than 45 minutes and final setting time should be less 10 hours of which the CSA-OPC pastes pass in final setting time. Here all, the blocks satisfy the BS12 (1978) [1] recommendation.

4.2. Effect of CSA on Density

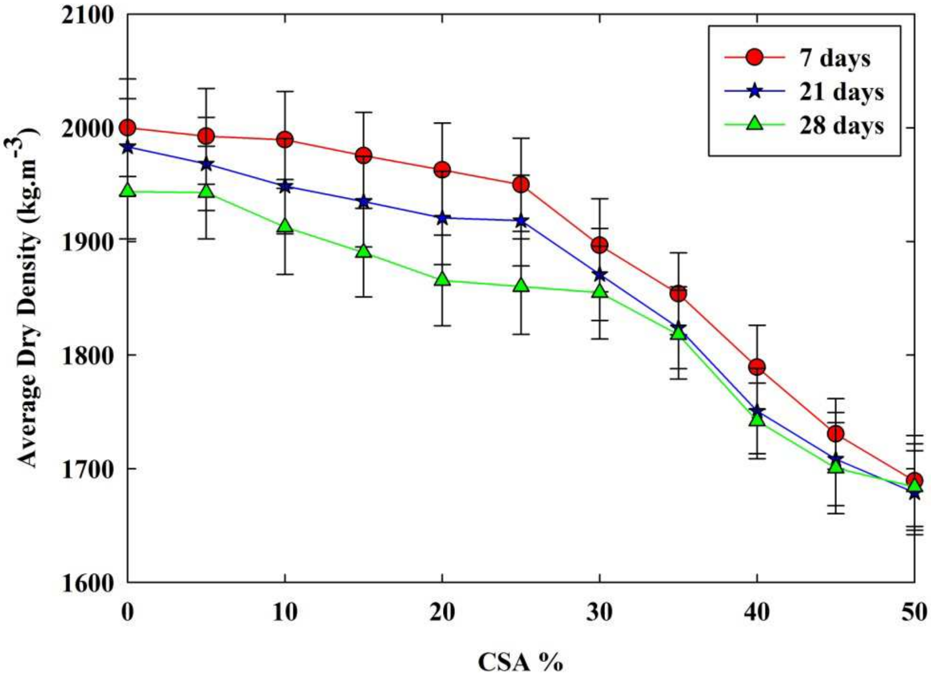

Figure 2. *The average dry density as a function of CSA doping percentage. The legend in the right hand side corner indicates the different age periods.*

As shown in Figure 2, the average density of the block decreases with the increase percentage of the CSA content. This is expected, since the density of cement is higher than that of the CSA. The blocks doped with 5 and 10% CSA satisfy the requirements as per BS 3921:1982 British standard specifications for cement block which stated the minimum density of 2000 $kg.m^{-3}$ [19]. Furthermore, the average density of the block decreases with increasing the curing days. This effect is due to the reduction of water content as well as the pores in the cement block.

4.3. Effect of CSA on Water Absorption

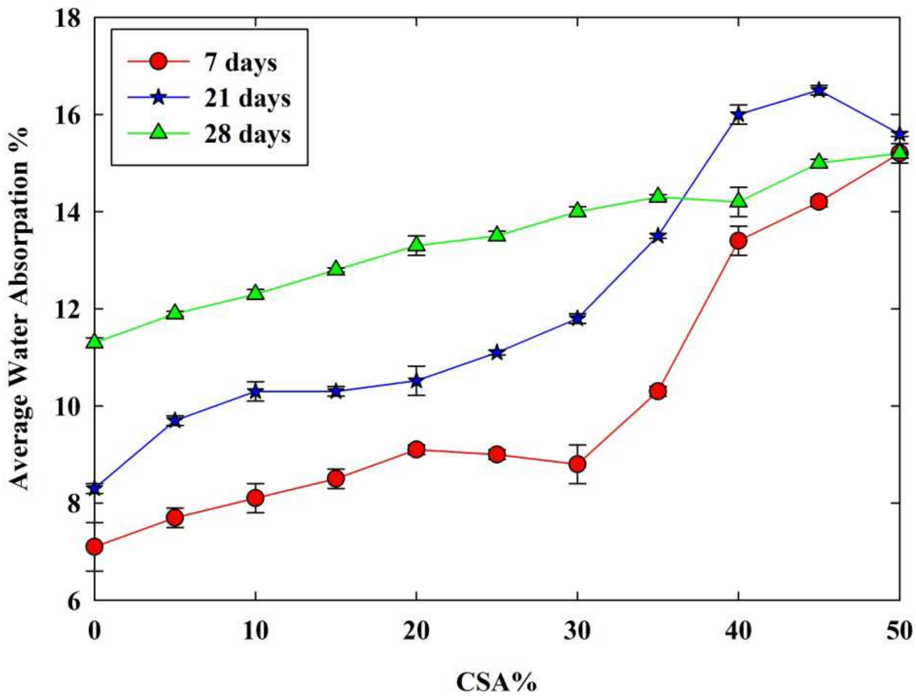

Figure 3. *The average water absorption as a function of CSA doping percentage. The legend in the left hand side corner indicates the different age periods.*

In the present research, water absorption increases with increasing the CSA% as well as the curing days as shown in Figure 3. Considering the conventional cement block, water absorption found in the present study is 11.3% at 28 days which is slightly less than the BS 5628: Part 1:2005 [18] recommended value of 12% for conventional cement blocks. However, water absorption of the blocks that have 5 and 10% of CSA are 11.9 and 12.3, respectively, which is nearly equal to the recommended value of the conventional cement block. According to the data obtained, the increment of water absorption with the doping percentage might be due to the CSA: the porosity increases with doping of CSA.

The average compressive strength of the cement block decreases with increasing percentage doping of CSA. However, the strength increases with curing days can be seen in Figure 4. The 7 days strength decreases from 240 kg.cm^{-2} for conventional block to 30 kg.cm^{-2} for 50% doping with CSA. After 21 days curing, the strength of the block varies from 280 kg.cm^{-2} for conventional block to 66 kg.cm^{-2} for 50% of CSA. The strength after 28 days curing decreases from 320 kg.cm^{-2} for conventional block to 98 kg.cm^{-2} 50% doping with CSA. The optimal 28 days average compressive strength for the cement block is observed at 10% CSA doping (290 kg.cm^{-2}). However, after 28 days curing, the average compressive strength decreases with increasing the CSA doping percentage. The similar behavior can be seen for 7 and 21 days curing. The results obtained after 28 days curing, clearly indicate that, the compressive strength of the blocks, satisfied the minimum standard requirement of 280 kg.cm^{-2} according to BS 6073: Part 2: 1981 [20] up to 10% CSA.

4.4. Effect of CSA on Compressive Strength

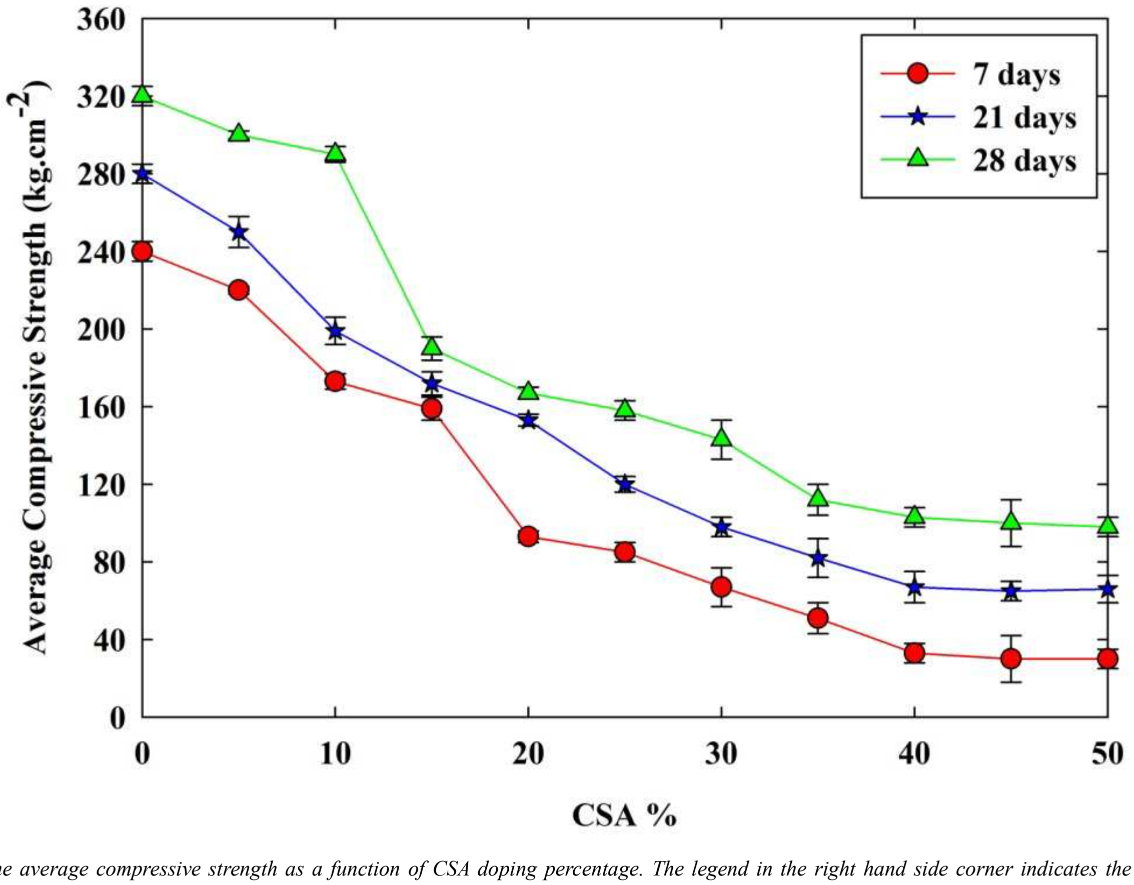

Figure 4. *The average compressive strength as a function of CSA doping percentage. The legend in the right hand side corner indicates the different age periods.*

The average compressive strength of the cement block decreases with increasing percentage doping of CSA. However, the strength increases with curing days can be seen in figure 4. The 7 days strength decreases from 240 kg.cm^{-2} for conventional block to 30 kg.cm^{-2} for 50% doping with CSA. After 21 days curing, the strength of the block varies from 280 kg.cm^{-2} for conventional block to 66 kg.cm^{-2} for 50% of CSA. The strength after 28 days curing decreases from 320 kg.cm^{-2} for conventional block to 98 kg.cm^{-2} 50% doping with CSA. The optimal 28 days average compressive strength for the cement block is observed at 10% CSA doping (290 kg.cm^{-2}). However, after 28 days curing, the average compressive strength decreases with increasing the CSA doping percentage. The similar behavior can be seen for 7 and 21 days curing. The results obtained after 28 days curing, clearly indicate that, the compressive strength of the blocks, satisfied the minimum standard requirement of 280 kg.cm^{-2} according to BS 6073: Part 2: 1981 [20] up to 10% CSA.

4.5. Effect of CSA on Flexural Strength

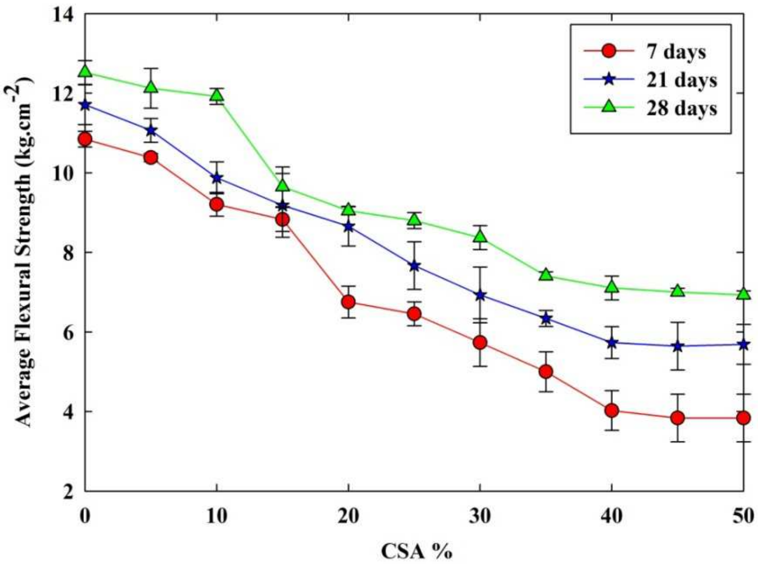

Figure 5. *The average flexural strength as a function of CSA doping percentage. The legend in the right hand side corner indicates the different age periods.*

The average flexural strength of cement blocks is plotted as a function of various CSA doping percentage in Figure 5. It can be clearly seen that when doping the mixture with CSA a significant decrease in flexural strength is obtained. However, it can be seen that when the curing days increases a significant increase in flexural strength. At the age of 7 days, flexural strength decreases from 10.84 kg.cm^{-2} for 0% CSA cement block to 3.84 kg.cm^{-2} for 50% doping with CSA. At the age of 21 days curing, the flexural strength of the cement block changes from 11.72 kg.cm^{-2} for 0% CSA cement block to 5.69 kg.cm^{-2} for 50% of CSA. The flexural strength at the age of 28 days curing falls from 12.52 kg.cm^{-2} for 0% CSA cement block to 6.93 kg.cm^{-2} 50% doping with CSA. The optimum average flexural strength is observed at 10% CSA doping (11.92 kg.cm^{-2}) at the age of 28 days. However, at the age of 28 days, the average compressive strength decreases with increasing the CSA doping percentage. The similar behavior can be seen at the age of 7 and 21 days. The results obtained at the age of 28 days, evidently indicate that, the flexural strength of the blocks, satisfied the minimum standard requirement of 12 kg.cm^{-2} according to BS 6073: Part 2: 1981 [20] up to 10% CSA.

4.6. Relationship between Compressive Strength and Flexural Strength

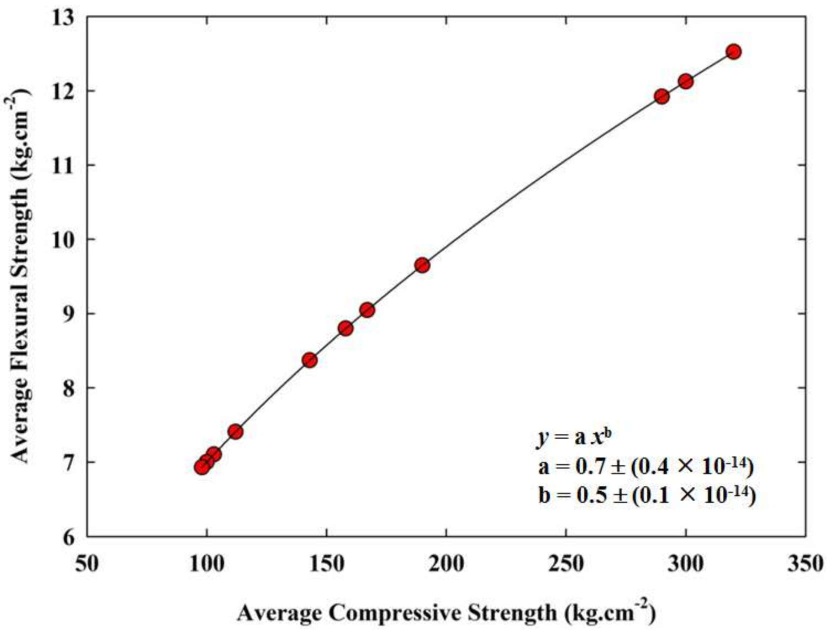

Figure 6. *The relationship between average compressive strength and flexural strength of the CSA mixed cement blocks.*

Relationship between the average compressive strength and the average flexural strength of the CSA doped cement blocks at the age of 28 days are shown in the figure 6. The relationship between the compressive and flexural strength is given by $F_t = 0.7(F_{ck})^{0.5}$ for normal light weight cement blocks. Where F_t is the flexural strength and F_{ck} is the compressive strength of the cement block. The power law fit to the data points satisfy the relationship in the form $y = a\, x^b$, where a = 0.7 ± (0.4×10^{-14}) and b = 0.5 ± (0.1×10^{-14}). These constants can be varied with respect to the type of cement blocks.

5. Conclusion

The main conclusions derived from this investigation are as follows:

1. Agriculture wastes such as coconut shell ash show a good pozzolanic property in the engenderment of cement blocks.
2. The optimal average dry density of 10% CSA satisfies the requirements as per BS 3921: British standard specifications for cement block which stated the minimum density of 2000 kg.m^{-3}.
3. The maximum dry density of 1943.00 kg.m^{-3} was recorded at 5% supersession at 28th day. The dry density of the Portland cement / CSA concrete blocks generally decreases as the percentage of CSA content increases although the average dry density shows a remarkable decrease after 25% CSA.
4. The maximum compressive strength of 300 kg.cm^{-2} was recorded at 5% supersession at 28th day. The compressive strength of Portland cement / CSA concrete blocks generally decreases as the percentage of CSA content increases.
5. The results obtained after 28 days curing, clearly indicate that the compressive strength of the blocks, satisfied the minimum standard requirement of 280 kg.cm^{-2} according to BS 6073: Part 2: 1981 for the optimal value of 10% CSA.
6. The maximum flexural strength of 12.12 kg.cm^{-2} was recorded at 10% supersession at 28th day. The compressive strength of Portland cement / CSA concrete blocks generally decreases as the percentage of CSA content increases.
7. The results obtained at the age of 28 days, evidently indicate that the flexural strength of the blocks, satisfied the minimum standard requirement of 12 kg.cm^{-2} according to BS 6073: Part 2: 1981for the optimal value of 10% CSA.
8. The power law fit obeys the relationship $y = a\, x^b$, where a = 0.7 ± (0.4×10^{-14}) and b = 0.5 ± (0.1×10^{-14}). These constants can be varied with respect to the type of cement blocks.
9. Coconut shell ash doping should not exceed 10% of the weight of cement for best results.

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