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Coconut Shell Ash as Cementitious Material in Concrete: A Review

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ABSTRACT

In recent years, there has been great concern about introducing new supplementary cementitious materials (SCM) in place of ordinary Portland cement (OPC) in concrete. The aim of this study is to check the behavior of coconut shell ash (CSA) with various proportions in concrete. Coconut shell is available in abundant quantity in local agricultural fields and considered as waste product. On the other hand, cement production emits a lot of toxic gases in the atmosphere which causes environmental pollution and greenhouse gases. Thus, CSA might be utilized as a cementitious material in concrete for sustainable development. This review article provides a detailed overview of the fresh and mechanical properties of various research studies. It is found that by incorporating the 10% of CSA into concrete results in the improvement of mechanical properties of concrete such as compressive, split tensile strength and flexural strength of concrete after every curing day respectively. Moreover, the modulus of elasticity enhanced while using 10% of CSA in concrete and the workability of fresh concrete was declined as the percentage of CSA increases. In addition to that, the use of CSA in concrete can reduce the total carbon foot print while reducing the overall cost of concrete manufacturing.

Keywords: Coconut shell ash; cement replacement material; mechanical properties; reduce the environmental issue

INTRODUCTION

Concrete is the most versatile and most widely used construction material worldwide. Concrete is the best building material as compared to stone, brick or steel, etc. (Akyuncu 2012; Bheel et al. 2012). Civilizations as old as from 6500 BC have used non-hydraulic cement in the past. Greeks and Romans developed hydraulic cement afterward (Li 2011). It is the most used construction material these days because of its numerous merits which encircle but are not limited to its moldability, adaptable nature, fire resistance, and affordability. Concrete is used in many types of construction like houses, roads, bridges, hospitals and commercial centers, etc. Concrete is a combination of cement, coarse aggregate, fine aggregate, water, and admixtures. More than 10 billion tons of concrete are produced annually (Evi Aprianti S 2017). With the rise in demand for other basic needs of human-like clothing, energy, food, and water. Similarly, the demand for concrete is also expected to rise by the year 2050 by which the estimated production of concrete is about 18 billion tons annually (Evi Aprianti S 2017).

Due to the large use of concrete, the demand of cement is also increasing with every passing day. The present use of cement is evaluated to be around 12 million tons per year and is yet expanding day by day (Khitab 2020). The production of cement is very hazardous to the environment as it produces heat and an excessive amount of CO_2 (Bheel et al. 2020). Carbon dioxide emissions are a serious environmental problem in cement production (Mangi et al. 2019). It is a well-known fact that the production of one-ton cement exhaust around one ton of carbon dioxide directly into the atmosphere (Mangi et al. 2019). Besides, it is accused of producing cement for 5-7% of carbon dioxide emissions from industrial sources (Bheel et al. 2020). Similarly, the materials required to produce the cement also pollute the environment and cause the depletion of our natural resources (Mangi et al. 2019). Other constituents of concrete can also pollute the environment like coarse aggregates, which are obtained by cutting and blasting of hills and mountains. Previously most of the researchers have already worked a lot to reduce the use of concrete and replace concrete with such suitable materials, which give the properties like the concrete. The emphasis is being put forth on the utilization of industrial and agricultural wastes, as they are the environmental burden (Batayneh et al. 2007; Senthamarai and Manoharan 2005).

It is difficult to dispose of agricultural waste because it still creates an environmental burden. However, it is beneficial when used in concrete. It will not only save money, but it will also cause a reduction in the use of cement in the concrete structure in order to reduce the carbon dioxide emissions associated with cement production, and the stability of the building must be taken into account (Hanle et al. 2004; Ma et al, 2007; Aitcin 2011). Partial replacement of cement by a combination of materials for the replacement of cement (CRM) is not only economically advantageous but also beneficial due to its mechanical, durable, and microstructural characteristics (Gruber et al. 2001). The use of CRM's in concrete has attracted people's attention, and its focus is on extending the life of concrete structures (Kumar et al. 2017). There are many CRMs available in the market for concrete. Some of the most common materials are bagasse (SCBA), limestone powder (LSF), rice husk ash (RHA) (Bheel et al. 2019) and silica fume (SF), etc. (Ghosal 2015). In this research project, coconuts shell ash (CSA) is used as agricultural waste. This waste is readily available as there is no other use of this for landfilling. Owing to the environmental issues associated with cement, the partial replacement of cement by a local waste material will not only lessen the requirement of cement in construction projects but also the corresponding dumping of the waste in landfills will be reduced. It was evaluated that CSA has the capability to partially replace cement in concrete. The resulting concrete was evaluated in terms of various fresh and mechanical properties. There are several studies conducted by many researchers on the strength development of concrete containing CSA in concrete. Their works have revealed that the utilization of CSA showed considerable enhancement in strength development.

Hasan et al. (2016) conducted the investigational research on hardened concrete binary blended with stone dust (SD) and coconuts shell ash (CSA). In this study, the numbers of specimens were cast for mechanical properties. It was showed the crushing strength, flexural test, and shrinkage test of concrete increased by 7.5%, 3.5%, and 53% while cement replaced with 10% of CSA and SD after 28 days. Kumar et al. (2017) reported that the use of various ratios of CSA and Eggshell powder (ESP) mixed in concrete to investigate the hardened concrete. It was showed the compressive, flexural, and tensile strength test augmented by 8%, 14.15%, and 8.5% at 10% of CSA and ESP as a substitute for cement. Utsev et al. (2012) investigated the study on the crushing strength of concrete inclusion with 0%-30% of CSA. The conclusion demonstrated that the 10% replacement was optimum where the compressive strength improves beyond it decreases. Bhartiya and Dubey (2018) studied the effects of CSA and ESP content on the crushing strength of concrete. It was pointed out that the crushing strength was improved by substituting 10% CSA and ESP in concrete.

The main purpose of this review study is to investigate the impact of CSA on the fresh and mechanical properties of concrete. The particular objectives of the review studies are highlighted below:

1. To know the influence of CSA on the workability of concrete.
2. To examine the impact of CSA on compressive, split tensile, and flexural strength of concrete.
3. To know the behavior of CSA on the mechanical concrete (Modulus of Elasticity).

SOURCES AND PROCESSING OF COCONUTS SHELL ASH (CSA)

Coconut is known as "the most useful tree for humanity", "king of tropical plants" and "tree of life". Coconut or its scientific name, Cocos Nucifera, is the most significant cultivated palm tree and extensively distributed among all palm trees. Coconut is a tall cylindrical stem palm, 30 m high, and 60-70 cm in diameter (Gummadi 2012). It is a tropical plant at a low height. It requires sunlight and soil rich in calcium and phosphorus, so it is usually suitable for cultivation on sandy shores. The coconut tree is one of the most useful plants in the world. Coconuts are grown in 92 countries in the Globe. The world coconut production is 51 billion nuts from an area of 12 million hectares. Consider Southeast Asia Like the origin of coconut. The four main countries, India, Indonesia, the Philippines, and Sri Lanka, contributed 78% of World production (Gummadi 2012).

World coconut production was 61.5 metric tons, of which Indonesia, the Philippines, India, Brazil, and Sri Lanka as the main contributor to coconut production (Gunasekaran et al. 2015). The total area of coconuts in the world was estimated in the Asia-Pacific region, there are about 12 million hectares, which is around 93%. The annual production of coconuts was estimated at 10 million tons of coconut copra equivalent. Globe production of coconut, more than 50% is processed into dried coconuts (Jalal et al. 2012; Ahlawat, and Kalurkar, 2012). Coconut shell is one of the most vital natural fillers produced in tropical countries such as Malaysia, Indonesia, Thailand, and Sri Lanka. Much work is devoted to the use of other natural fillers in composite materials. In recent years, coconut shell fillers have been potential candidates for the development of new composite materials because they have additional advantages, such as high strength, modular characteristics, and high lignin content. The high lignin content makes the composites made using these fillers have better weather resistance and therefore higher weather resistance suitable for use as a building material.

Coconut Shell Powder is also widely used in production Such as decorative materials, ropes, etc. Due to its low cellulose content, the shell also absorbs less water (Gummadi 2012). This study focus on the study of increased efficiency of coconut shell particles as a natural material for reinforcing epoxy resins towards their Flexural properties. Coconut shells have no economic value, and their disposal is not only expensive but can Ecological problems. Coconut shell is suitable for making carbon black due to its excellent natural structure and low ash quantity. Coconut shell is a waste product obtained from the agricultural industry. This Coconuts shell was burnt under controlled combustion arrangement at 500 °C to 550 °C temperatures for two hours to produce ash. The coconut shell ash was sieved through #200 sieves as shown in Figure 2 and it can be used as a cement replacement material in concrete. The experimental results conducted on CSA were obtained from previous studies as tabulated in Table 1.

TABLE 1. Physical Properties of Cement and CSA (Gummadi 2012)

S.No	Property	Cement	CSA
01	Normal Consistency	34%	38%
02	Specific Gravity	3.15	1.33
03	Water Absorption	----	25%
04	Fineness Modulus	5%	8%

FIGURE 1. Coconut Shell

FIGURE 2. Coconut Shell Ash (Barveen 2018)

SETTING TIME OF CSA PASTE

Table 2 shows that the setting time increases with the rise in content of the CSA. The initial setting time was increased from 74 minutes at 0% to 346 minutes at 30%. The final setting time has been increased from 96 minutes to 492 minutes. However, BS 12 (1978) is recommended that the initial and final setting times do not exceed 45 minutes and 10 hours respectively (Terungwa 2018). The previous report was presented by Arel et al. (2018) that the initial and final setting time was enhanced as the content of CSA increase in the paste. The same trend was followed by Fernando et al. (2017) that the initial and final setting was augmented with the inclusion of CSA in the paste.

POZZOLANIC PROPERTY AND CHEMICAL CHARACTERISTICS

Volcanic ash activity is the most characteristic feature of additional cement materials. It has the capability to consume calcium hydroxide and form calcium silicate hydrate (C-S-H). There are many ways to measure the pozzolanic properties of a material, but the chemical composition of the material can help to understand the pozzolanic potential of the material.

According to ASTM C618, the chemical composition of pozzolanic materials should be about 70%, which contains silicon dioxide, alumina, and iron oxide. As a rule, a chemical analysis of coconut shell ash shows that it contains a major amount of these elements. Therefore, this indicates that volcanic ash is more active. Silica in OPC (commonly called silica) is the main component responsible for the strength of early concrete and mortar. Hence, a large amount of silica in the CSA indicates that it is a cementitious material and can be used as a substitute for OPC. According to the chemical property requirements specified in ASTM C618, CSA can be classified as class N pozzolan. Class N volcanic ash is an unprocessed or calcined natural pozzolan that meets specified requirements and contains a certain diatomite, such as opaque stone and slate, volcanic ash, or pumice, as well as some clay and slate that need to be calcined. The loss of combustion is lower than the standard of 10% for class N volcanic ash. This indicates that the amount of unburned carbon in the CSA is very small. This is an ideal characteristic of N-type volcanic ash because if the percentage of losses during combustion exceeds 10%, this indicates the presence of a large amount of unburned carbon in volcanic ash, which will lead to a decrease the pozzolanic activity (Nagarajan et al. 2014). A decrease in pozzolanic activity can lead to a decrease in concrete strength. On the other hand, the moisture content in CSA exceeds the minimum requirements for volcanic ash of class N, so it is recommended to dry in the oven before using CSA (Adajar et al. 2020). The chemical composition of the binder is shown in Table 03.

SCANNING ELECTRON MICROSCOPY (SEM)

Scanning electron microscope (SEM) was (Gunasekaran et al. 2012) apt with an Oxford INCA dispersion spectroscopy system. The test was carried out at an accelerating voltage of 5 to 20 kV (Oluwasola et al. 2015). SEM analysis is for

TABLE 2. Setting Time of CSA Paste (Terungwa 2018)

S.No	CSA Replacement (%)	Initial Setting Time (Mins)	Final Setting Time (Mins)
01	0CSA	74	96
02	5CSA	142	239
03	10CSA	262	345
04	15CSA	273	384
05	20CSA	295	458
06	25CSA	327	476
07	30CSA	346	492

TABLE 3. Chemical Composition of CSA and Cement

Constituent	OPC (Noor-ul-Amin 2010)	CSA (Kumar et al. 2017)	CSA (Gummadi 2012)	CSA (Arel et al. 2018)	CSA (Fernando et al. 2017)	CSA (Isah 2014)
SiO_2	20.78	37.90	37.97	42.50	43.50	44.05
Al_2O_3	5.11	24.12	24.12	17.70	15.20	14.60
Fe_2O_3	3.17	15.48	15.48	8.17	12.60	12.40
CaO	60.89	4.98	4.98	4.30	3.25	4.57
MgO	3	1.89	1.89	0.71	15.01	14.20
Na_2O	0.25	0.95	0.95	0.93	0.47	0.45
K_2O	0.39	0.83	0.83	0.82	0.49	0.52
P_2O_5	0.26	0.32	0.32	--	0.40	--
SO_3	1.71	0.71	0.71	0.55	--	--
Loss on Ignition	2.31	11.94	11.94	6.51	8.39	8.89

discrete CS units and continuous CS units. The result shown in Figure 3 is that CS has very close discrete cells, 16.36 µm and 29.33 µm, respectively, and the pore size is from 760 nm to 1.64 µm. Also, the CS width with continuous cells is from 7.35 to 8.88 µm, and the thickness is from 852.7 to 1.24 µm. All results show that the CS sample can withstand higher loads and has higher crush resistance and wear resistance. It was also observed from the SEM images that CS is porous in nature and rough in texture and resulting in higher water absorption. Besides that, the results of (Gunasekaran et al. 2012) in Figure 4 (a) and Figure 4 (b) are CS samples with and without soaking. Figure 4 (b) shows that CS has a high water absorption capacity because it absorbs water and stores it as a pore structure inside CS, as a reservoir. Figure 5 is the SEM analysis for the CSA that was observed that its structure is solid in nature but irregular in size (Ting et al. 2016).

X-RAY DIFFRACTOMETER (XRD)

The chemical composition of the phase-in CSA was determined using a Philips X-ray diffractometer. Radiographs were obtained using Cu Kα radiation with a scanning speed of 3°/min. The CSA compound is SiO2, and the elements present therein are C, Mg, O, Al, Fe, Si, Zn, Na, and K indicate that the ash does not contain radioactive materials such as Dy, Xe, Pr, and Eu. The XRD results shown in Figure 6 are consistent with the obtained XRF results (Ting et al. 2016).

FOURIER TRANSFORM INFRA-RED (FTIR)

Coconut shell ash was tested for functional groups using an FTIR-8400S infrared spectrophotometer with Fourier transform (SHIMADZU). Figure 7 shows that, due to the presence of quartz in the initial gray bands at 1132 and 443.64 cm^{-1}, the IR spectrum increased (Madakson et al. 2016). A series of bands of about 3797 cm^{-1} displays the presence of mullite and a series of bands of about 4091.15-14617.74 cm^{-1} indicate the existence of carbon groups. It was confirmed that the mullite phase, quartz phase, carbon phase, and vitreous phase because the bands of multiphase ash, glassy, and quartz phase intersect between 1220 cm^{-1} and 1434.12 cm^{-1} (Ting et al. 2016).

EFFECT COCONUTS SHELL ASH ON FRESH PROPERTIES OF CONCRETE

SLUMP TEST

The demand of water for the workability of concrete is governed by particle fineness and its characteristics [39]. With constant water to blinder ratio, the workability reduces with the utilization of CSA as cement additional in concrete. The previous research also indicated that to achieve desired slump vales, the demand of water increases with the usage of CSA as cement replacement in concrete. The following examples are presented as evidence of a decrease in workability of concrete containing CSA.

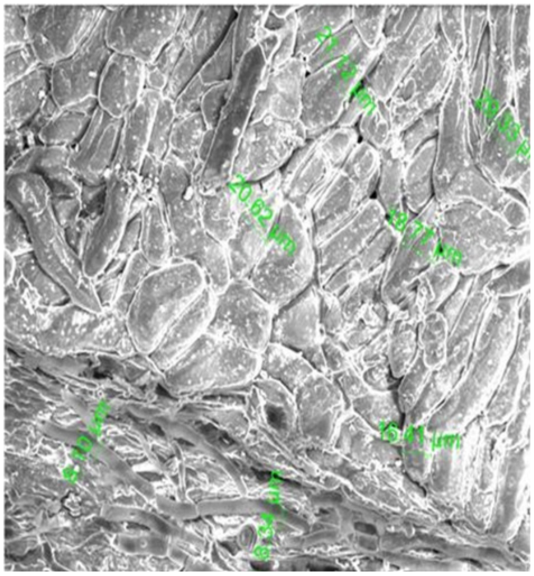

FIGURE 3 (a). Discrete Cells of CSA (Ting et al. 2016)

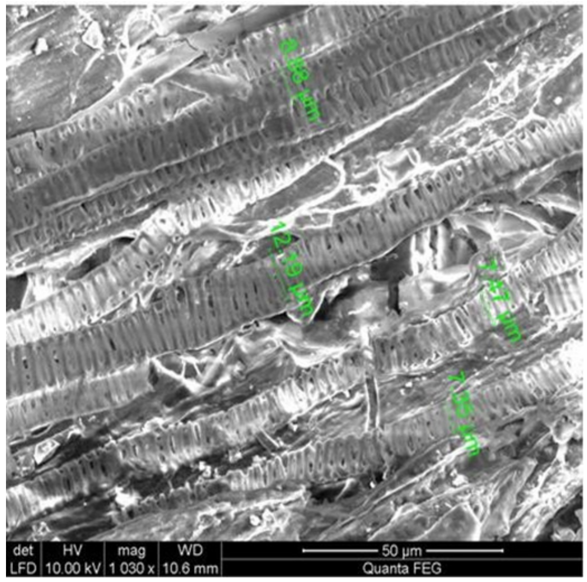

FIGURE 3(b) Continuous Cells of CS (Ting et al. 2016)

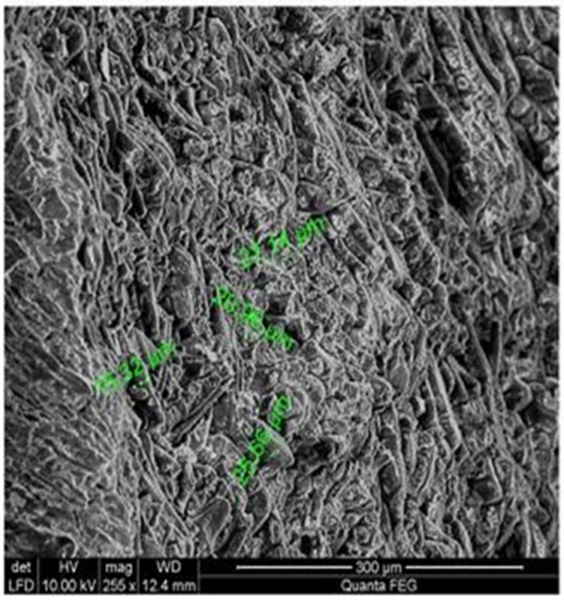

FIGURE 4(a). CS without Soaking (Ting et al. 2016)

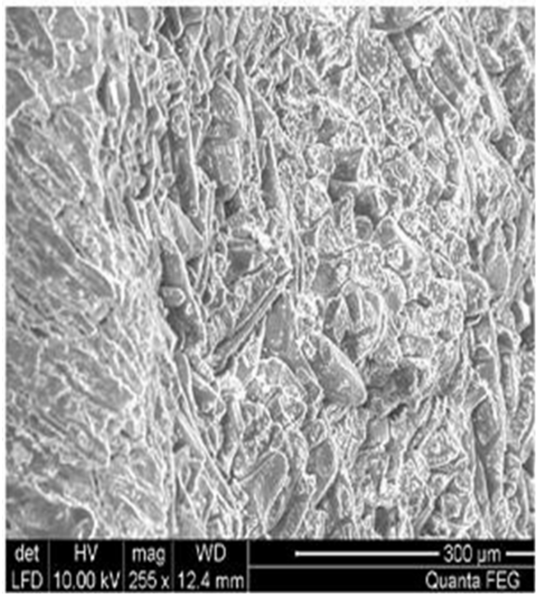

FIGURE 4(b). CS with Soaking (Ting et al. 2016)

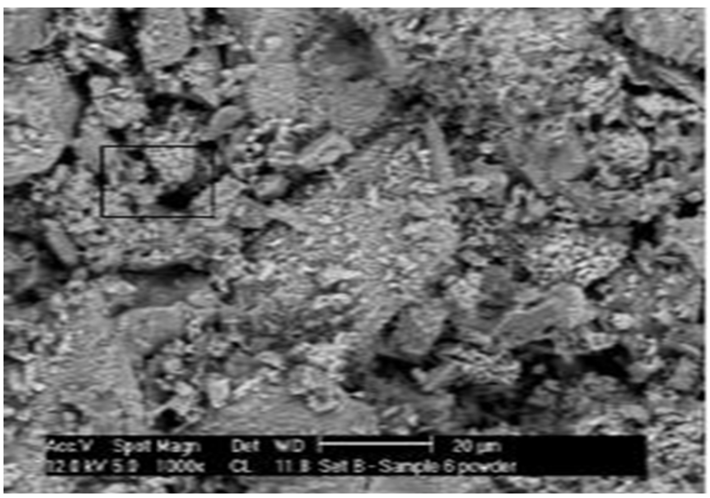

FIGURE 5. SEM of CSA (Ting et al. 2016)

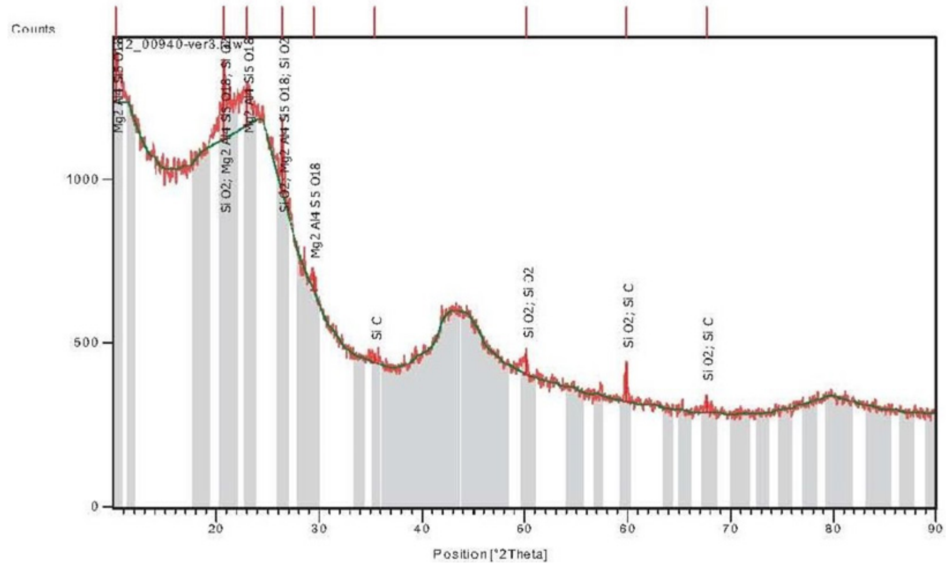

FIGURE 6. XRD pattern of coconut shell ash (Ting et al. 2016)

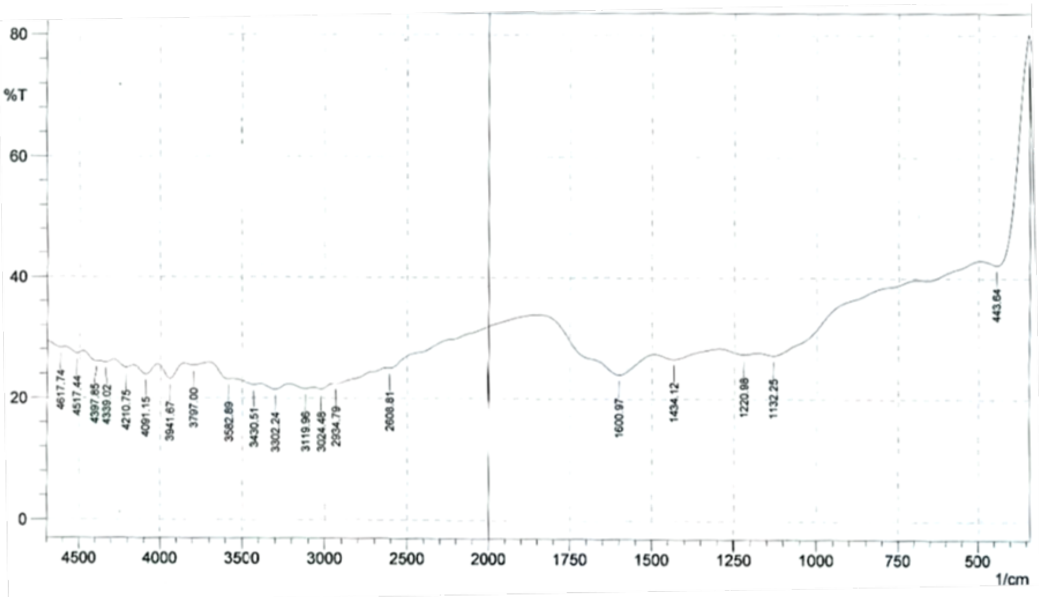

FIGURE 7. FTIR pattern of coconut shell ash (Ting et al. 2016)

Sanjay Sen et al. (2015) investigated the influence of coconuts fiber ash (CFA) as cement replacement in concrete and they found lower workability in the concrete mix due to coconuts fiber ash. They highlighted this performance due to rough surface and irregular particle size of CFA which significantly changes the texture of the concrete mix. Therefore, it increases the internal friction of particles which is liable for the low flow of fresh concrete. The optimum slump was concluded by 110 mm at 0% of CSA and the lowest value was observed by 82 mm when using 25% of CSA replaced with cement. The trend of workability can be given in Figure 8. The results trend noted by Barveen et al. (2018) that the workability was reduced as the amount of coconuts shell increases in concrete. Lehman et al. (2017) displayed that if the proportions of added coconut shell proliferations the workability of the concrete mix decreases. This result may be due to the relatively high water absorption of the coconut shell compared to conventional placeholders. Oyedepo et al. (2015) declared that water requirement for the concrete is increased due to the addition of coconuts shell in concrete. However, workability could be affected due to the reduction in the water content in the concrete mix. Whereas Ahlawat et al. (2014) examined the effect of coconuts shell as a partial coarse replacement on the workability of concrete, a fixed water-cement ratio the workability was found to decrease. This behavior indicated the internal particle friction and more water absorbed during the mixing of concrete, which caused a reduction in slump value. Similarly, Bhaskar et al. (2019) reported that the influences of coconuts shell used as aggregates in the concrete mix. The workability of concrete declined as the amount of coconuts shell increases.

It has been observed that using CSA as a substitute for cement in concrete can significantly reduce the workability of concrete due to its higher water absorption. Therefore, care should be taken while adopting water to blinder ratio in the concrete mix design.

EFFECT OF CSA ON MECHANICAL PROPERTIES OF CONCRETE

COMPRESSIVE STRENGTH TEST

The compressive strength of concrete is the main mechanical property of concrete, and all other mechanical properties are associated with it. Early studies showed that concrete without coconut fiber ash has a compressive strength of 20-30% higher than concrete with coconut fiber ash (Anifowoshe et al. 2016). Concrete incorporating no SCM and those with coconut shell ash and silica fume (SF) as 10% replacement of OPC have reported a higher compressive strength compared to those incorporating of CSA and SF at the 0% replacement level (Umamaheswari 2018). However, Bhaskar et al. (2019) reported a contradicting result indicating concrete incorporating coconut shell has a lower compressive strength compared to those without coconut shell concrete (Arel et al. 2018). Kumar et al. (Kumar et al. 2019) also reported higher compressive strength after 28 days. Replacing 10% OPC with CSA gave the maximum crushing strength. The study by Hasan et al. (2016) also supported that the maximum OPC replacement level with CSA and stone dust as 10% (5% CSA and 5% stone dust), as there might be detrimental effects on the properties of concrete after this replacement level. It was found that the OPC replacement level with CSA of less than 5% was not sufficient to increase the compressive strength at an early age (Arel et al. 2018). Maheswari et al. (2018) concluded from their studies that the optimal level of OPC replacement for CSA and SF is 10%, as there's lessening in compressive strength below and above this level at later ages. The decrease in compressive strength at levels above 10% was associated with an excess of silica available for reaction with calcium hydroxide formed in the cementitious matrix. The unreacted silica will remain in the matrix with a stable substance and will not stimulate any chemical reactions. Sharan and Raijiwala (2017) suggested that 10% replace CSA in a mixture of M 30, and strength of 42.89 N/mm^2 after 28th days, the Strength of concrete cubes will only increase when the maximum CSA replacement is 15%, but the strength by 15% will decrease with an increase in the percentage of CSA. Utsev et al. (2012) Collect and burn coconut shells that are considered environmental pollutants to produce coconut shell ash. Ash is used as volcanic ash and is partially replaced by cement in concrete production. Specific cubes were prepared using coconut shell ash instead of cement with a percentage of 0, 10, 20, and 30%, respectively. These concrete cubes were prepared for determining the compressive strength. The crushing strength on 28 days was calculated by 32.81 N/mm^2; therefore it meets the demand for its use as light and heavyweight concrete. The conclusion was drawn that the utilization of CSA as SCM up to 10-15% recommended being used as light and heavy concrete. Nagarajan et al. (2014) reported that when using CSA instead of OPC, the achieved compressive strength was reduced to OPC. Sharan and Raijiwala (2017) noted that the compressive strength of all mixtures increases with age. However, a substitution rate of 10% has the highest compressive strength at all ages. Bhartiya and Dubey (2018) also suggested that the optimal level for replacing OPC with CSA is 10% since an increase in the amount of CSA results in a decrease in compressive strength. It was previously agreed by Kumar et al. (2017) that the compressive strength was improved as the percentages of CSA rises up to 10% replacement of cement at 28 days, due to pozzolanic activity as shown in Figure 9.

Therefore, based on the previous input, it can be observed that the mechanical properties of the concrete/mortar containing CSA are suitable in comparison with the control mixture. It has also been found that the initial or later compressive strength of CSA concrete/mortar depends on the particle size of the CSA.

SPLIT TENSILE STRENGTH

Concrete has high compressive strength, but low tensile strength. However, in cases where the load will create stress on the concrete element, it is important to increase the tensile strength of concrete. The tensile strength of concrete is determined using a tensile test. According to reports, when CSA is used as a supplementary cementitious material in concrete, the tensile strength of the concrete is higher (Barveen 2018). Higher tensile strength is due to the effects of CSA in concrete as pozzolanic and filler. (Umamaheswari 2018) also reported an increase in tensile strength when cement was replaced with CSA and SF. It was found that the tensile strength of concrete mixed with CSA and SF was increased to an OPC replacement level of up to 10%. It shows the effect of particle size CSA and SF on the tensile strength of concrete. Reddy et al. (2014) perceived that there's a drop in the tensile strength with increasing replacement level of OPC with CSA. Gopinath et al. (2018) showed a decrease in split tensile strength when coconut shell used as coarse aggregates with the constant amount and rice husk ash used as cementitious material with varying in content. It was noticed that the split tensile strength decline with a rise in the amount of rice husk ash. Gummadi and Shirkanth (2012) also reported an increase in tensile strength to 10% CSA and SF. Kumar et al. (2017) observed an increase in split tensile strength up to 10% replacement of OPC with CSA and Eggshell powder as shown in Figure 10. Figure 11 presents the correlation between compressive strength and split tensile strength. It is evident from the figure that there is a good correlation between these two properties. Therefore, the equation presented in Figure 11 will be useful in estimating or predicting either the compressive strength or the split tensile strength if one of the values of the unknown if available.

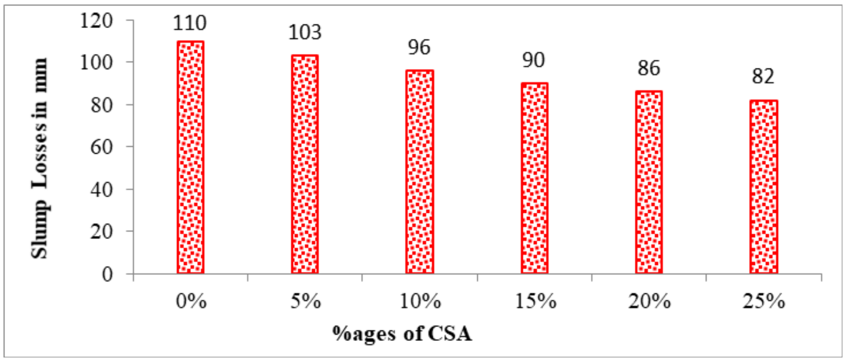

FIGURE 8: Workability Performance of Concrete Containing CSA (Adajar et al. 2020)

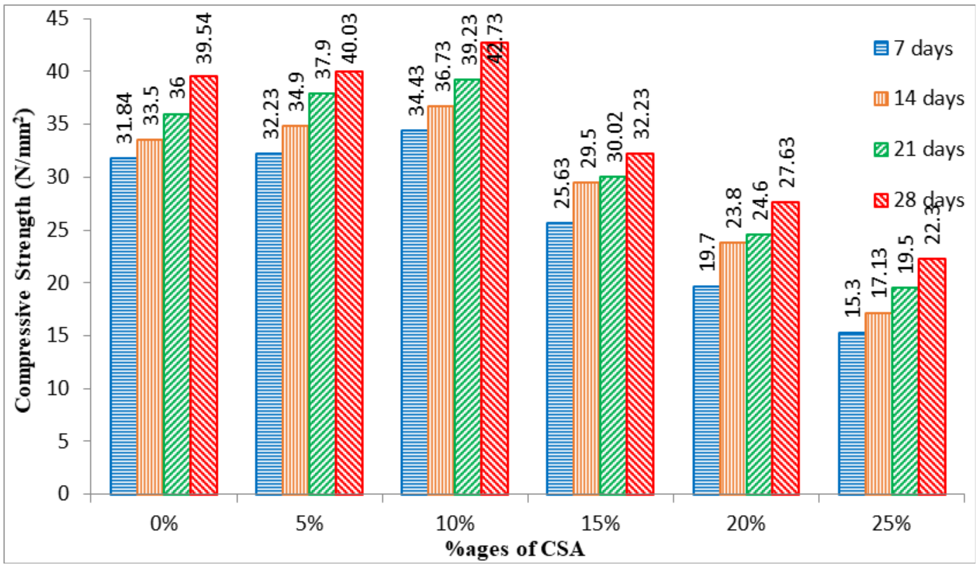

FIGURE 9: Compressive Strength of Concrete Containing CSA (Kumar et al. 2017)

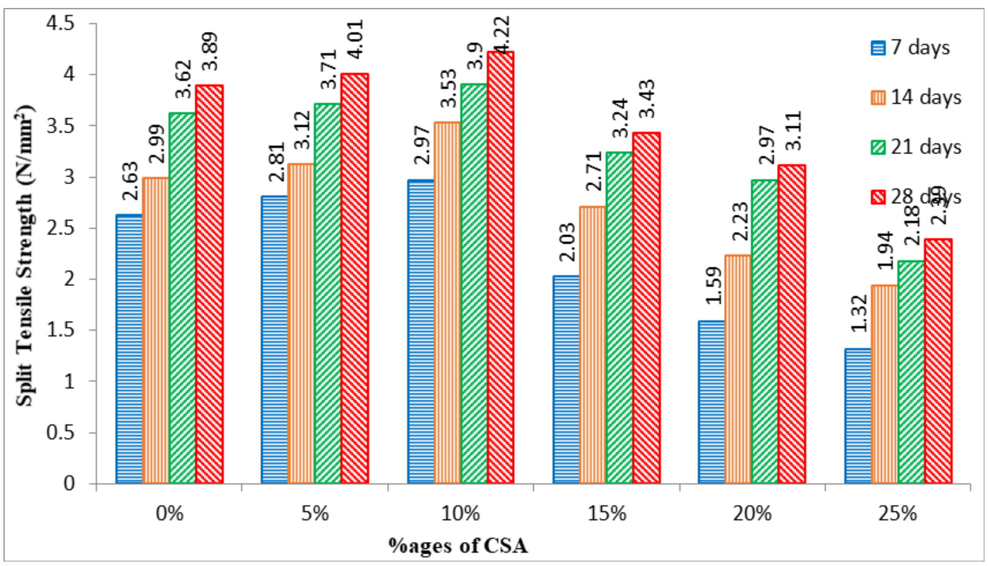

FIGURE 10. Split Tensile Strength of Concrete Containing CSA (Kumar et al. 2017)

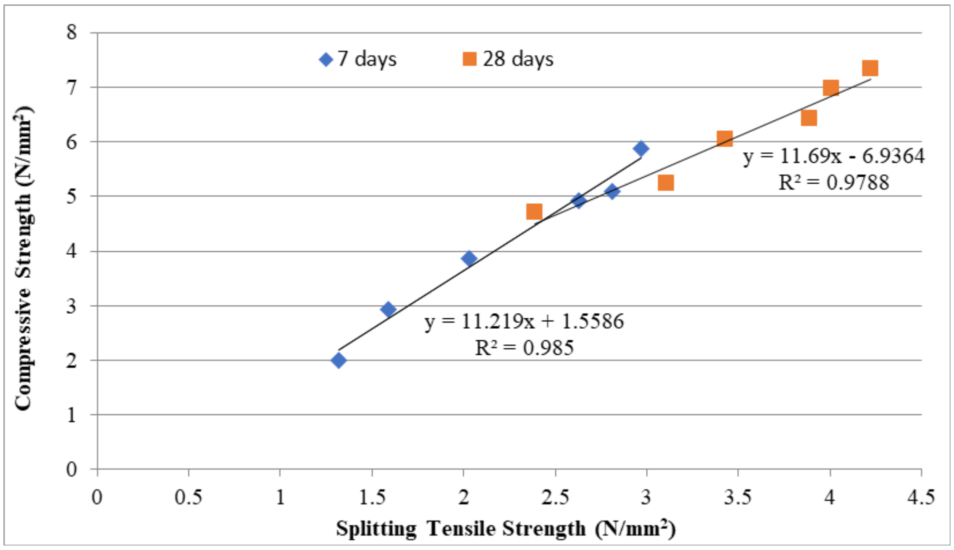

FIGURE 11. Correlation between Split Tensile Strength and Compressive Strength

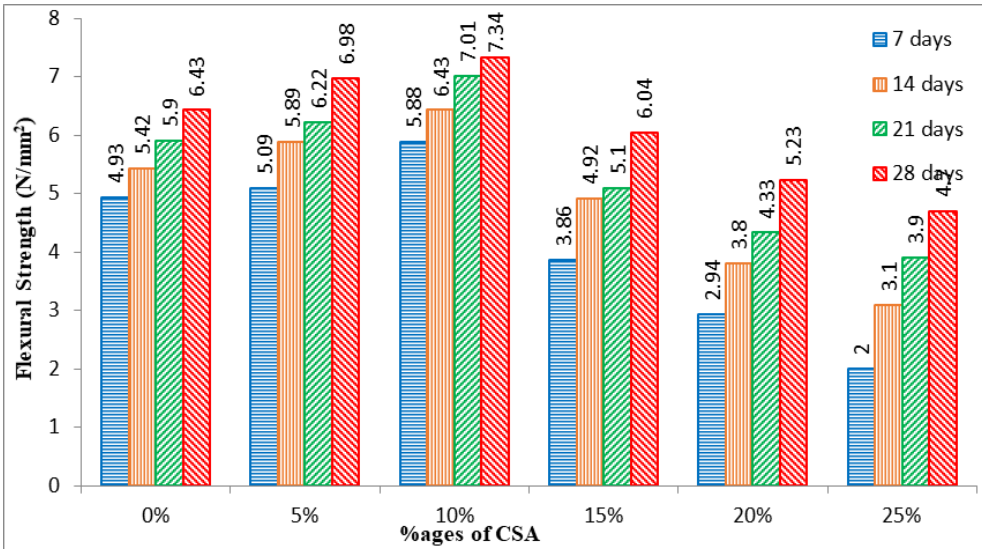

FIGURE 12: Flexural Strength of Concrete Containing CSA (Kumar et al. 2017)

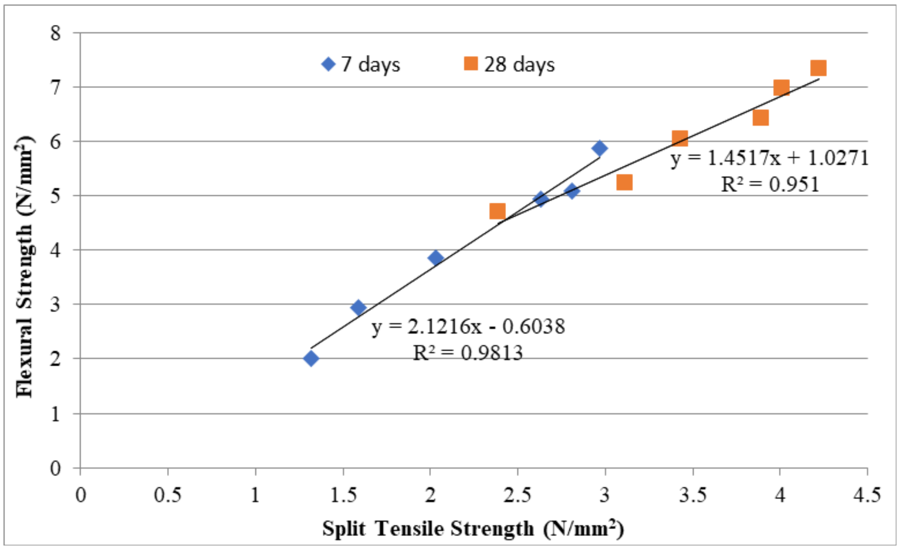

FIGURE 13: Correlation between Split Tensile Strength and Flexural Strength

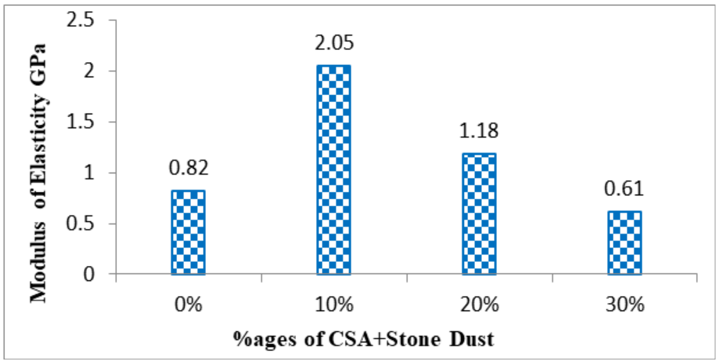

FIGURE 14. Modulus of Elasticity of Concrete Containing CSA (Hasan et al. 2016)

FLEXURAL STRENGTH OF CONCRETE

Flexural strength (also called modulus of rupture) is the ability of concrete to withstand deformation caused by bending. It was found that the flexural strength of concrete using CSA as a partial replacement for OPC is related to its tensile strength. Hassan et al. (2017) reported that CSA and stone dust were used to increase flexural strength up to 10% of the OPC replacement level. However, another study by (Umamaheswari 2018) showed that flexural strength increases when using 10% of CSA and SF instead of OPC. Barveen et al. (2018) informed that the flexural strength of concrete mixed with CSA as a partial replacement for OPC is low. (Anifowoshe et al. 2016) suggested that with a rise in the proportion of coconut fiber ash, the flexural strength of concrete decreases. Kumar et al. (2017) reported that when using CSA and eggshell powder instead of OPC, the flexural strength of concrete increased. This improvement is due to the properties of pozzolanic and filler properties of CSA and eggshell ash. Also, from Figure 12, it can be concluded that the flexural strength of concrete increases with a decrease in CSA particle size. Figure 13 shows the correlation between flexural strength and split tensile strength. It can be seen from the figure that there is a good linear correlation between these properties. However, there is a more linear correlation between flexural strength and tensile strength. Nonetheless, the two formulas in Figure 06 will be useful in predicting the properties of concrete mixtures incorporating CSA.

MODULUS OF ELASTICITY

The modulus of elasticity of concrete indicates its ability to withstand elastic deformation. Compared to concrete without CSA, concrete with CSA can partially replace OPC and exhibit a higher modulus of elasticity (MOE) (Barveen 2018). MOE increases with the level of substitution of CSA and the age of curing. This was also in agreement with the study by Hasan et al. (2016) where they found that the MOE increased with the replacement content of CSA and stone powder for OPC increased up to 20% as compared with conventional concrete. By incorporating CSA as a partial replacement for OPC, an increase in MOE is due to the fact that CSA particles can efficiently fill pores in the matrix due to their fineness. Pores are filling leads to a finer interfacial transitional zone between the filler and the adhesive matrix.

CONCLUSIONS

Based on this overview, the following conclusion can be made about the use of CSA in concrete.

1. The workability for all mixtures declined with the inclusion of CSA in concrete. This declined in workability is due to CSA absorbs more amount of water.
2. Replacing OPC with CSA in concrete can increase compressive, split tensile and flexural strength with time due to its pozzolanic properties. However, the recommended replacement with OPC is 10%.
3. The modulus of elasticity is achieved maximum at 10% of CSA utilized as a cementitious material in concrete at every curing period.
4. The use of CSA in concrete creates sustainable management of agricultural waste. Since OPC is one of the largest sources of carbon dioxide emissions. Thus, CSA can reduce concrete manufacturing costs and also lower carbon footprint.
5. In order to better understand, the mechanical properties of concrete in combination with CSA instead of OPC, with additional studies such as durability, permeability, and drying shrinkage of concrete) are still required.

DECLARATION OF COMPETING INTEREST

None.

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