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ORIGINAL ARTICLET

The influence of nucleus dates waste and ceramic wastes in sustainable concrete

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Abstract: Recycling has progressed recently, turning specific non-renewable resources into renewable ones. This has led to a considerable increase in research on using waste materials such as ceramic and nucleus date waste as alternative aggregate materials in buildings. They suggest using aggregate from nucleus dates rubbish and ceramic waste to reduce the amount of waste in the environment and address material shortages at building sites. This study was aimed at determining whether the incorporation of ceramic waste aggregates (CWA) and nucleus dates aggregate (NDA) instead of coarse aggregate can improve strength ultra-high-performance concrete (SHPC) properties. Ten SEC combinations were prepared: 10%, 20%, and 30% of NDA, CWA, or a combination of both. After testing, quartz powder (Q.P) or silica fume (S.F.) can increase the UHPC by enhancing its mechanical characteristics. Waste as construction materials could have substantial technological, economic, and environmental advantages when employed within a sustainable development framework. The study's conclusions proved that replacing NDA or CWA can improve the qualities of SHPC, especially when replacing 10% of the original material.

Keywords: Nature Coarse aggregate (NCG); nucleus dates aggregate (NDA); ceramic waste aggregates (CWA); sustainable high-performance concrete (SHPC)

1 Introduction

Because of its adaptability and cost-effectiveness, concrete is essential in contemporary construction. It is predicted to continue to be widely used in building activities. Concrete's composition can be modified by changing the proportions and constituents of its ingredients to meet certain specifications [1]. Recently, recycled aggregates have been adopted to conserve natural resources, reduce the volume of solid waste sent to landfills, and mitigate environmental impact. This approach promotes sustainability within the construction industry through resource recovery and reduced reliance on new aggregates [2, 3]. However, significant energy is needed when producing concrete [4], responsible for about 5% of worldwide CO2 emissions [5]. This happens because raw materials such as sand, gravel, and crushed rock are applied where annual global consumption amounts to 10-11 billion tons [6]; in cement production, approximately four G.J. per ton of cement is used annually. New ways to reduce energy use during concrete manufacturing are being investigated because of these environmental concerns. Replacing natural aggregates with recycled materials can

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make concrete more environmentally sustainable [7]. The date palm is crucial in the oasis agro-system, serving as its fundamental element. The distinguishing feature of this organism is a false stem called a stipe, which has the potential to grow to heights ranging from 30 to 40 meters [8]. Date palm plants possess exceptional versatility and provide many applications for every tree component, encompassing its fibers, kernels, fronds, leaves, and even the wicker material obtained from its branches.

Furthermore, dates possess inherent value as a highly nutritious food item. Fruits are abundant in vital components such as water, minerals, salts, vitamins, and carbs, rendering them a valuable nourishment source for people. [9, 10]. In 2022, Egypt ranked first among the world's five largest date-producing countries, with a production volume of 1,465,030 million tons. The country has considerable potential for exporting semi-dry date types, specifically Sewi and the recently introduced "Medjool" variety.

Nevertheless, despite a growing worldwide demand for dates, Egypt's exports in the global dates market are still minimal. [11,12]. It is feasible to recycle ceramic trash and transform it into valuable coarse aggregate to create concrete. The properties of ceramic waste as a coarse aggregate can closely resemble those of traditional aggregates commonly employed in concrete. The ceramic tile waste can yield coarse aggregate with properties resembling conventional concrete aggregates. This recycling method reduces the need for new aggregates, advocates for sustainable practices, and decreases the amount of garbage disposed of in landfills.[13, 14]. The ceramics industry traditionally estimated that the waste produced accounted for approximately 8 to 10 percent of its daily production. With the accumulation of ceramic tile waste increasing daily, the ceramic industries urgently need to discover a resolution.[15-17] [18]. Ceramic waste materials possess constituents that have the potential to improve the compressive, tensile, and flexural strengths, as well as the elastic modulus, of concrete. [18, 19].

Furthermore, using ceramic waste in concrete can improve its resistance, increasing its durability [20, 21]. Similarly, utilizing traditional waste materials in concrete production would produce more resilient concrete and environmentally friendly outcomes. Implementing modernizations in concrete construction can effectively decrease the consumption of natural resources and facilitate the discovery of alternative options. Using alternative materials leads to cost reductions, energy preservation, the creation of potentially superior products, and substantial environmental risks [22].

This study introduces a novel type of aggregate called the Light Aggregate, derived from the Using Nucleus. This development aims to promote sustainability and the Use of environmentally friendly materials by replacing natural coarse aggregate with ceramic wastes. Additionally, an important consideration is to ensure that the strength of concrete is maintained without any reduction [23, 24]. Ten conventional concrete mixes were made and poured to attain this objective; the control mix, referred to as the first mix, was designed to possess a strength of 93.4 MPa. This study examines the performance of modified concrete by using nucleus dates waste and ceramic waste as partial replacements for natural coarse aggregate aggregates. The rates of replacement tested are 10%, 20%, and 30% for each material. The slump test was used to control the parameters of fresh concrete, while measurements of compressive strength after 7, 28, and 91 days, flexural strength tests at 91 days, splitting strength at 91 days, modulus of elasticity at 91 days, and cost analysis for sustainable economic concrete (SEC).

1 Research significance

The market for ceramic tiles in Egypt has a lot of potential. There are now 32 ceramic tile and sanitary ware plants in Egypt, and more are under construction [23]. The ceramic and refractory industries comprise 7% of all Egyptian industries and are two of the country's seven most important and promising sectors. The manufacturers examined the wastes generated by three different ceramics industries [24, 25]. Conversely, palm and date residues are seen as plant crops, crops, factories, and factories that canne date; they are also regarded as kernels and infected, deformed, or deformed dates unfit for sale and canning. A survey of some palm tree farms revealed that each palm produces an average of 23 kg of waste annually, indicating the enormous volume of unused waste that poses a severe environmental threat to the countries that make it. This led to the need to identify a set of transformation projects for the waste date harvest. New techniques are being investigated to reduce the quantity of waste generated in the production of concrete because of these environmental concerns.

2 Experimental Work

Presently, Egypt makes fresh concrete elements from garbage. Business waste could be successfully reduced, and the carbon footprint of building materials could be decreased if concrete is produced locally and mixed with industrial and agricultural trash. **Fig. 1** illustrates the practical programming implemented to make high-performance concrete that is environmentally friendly. The combinations according to the NDA and CWA components in concrete are shown in **Fig. 1**.

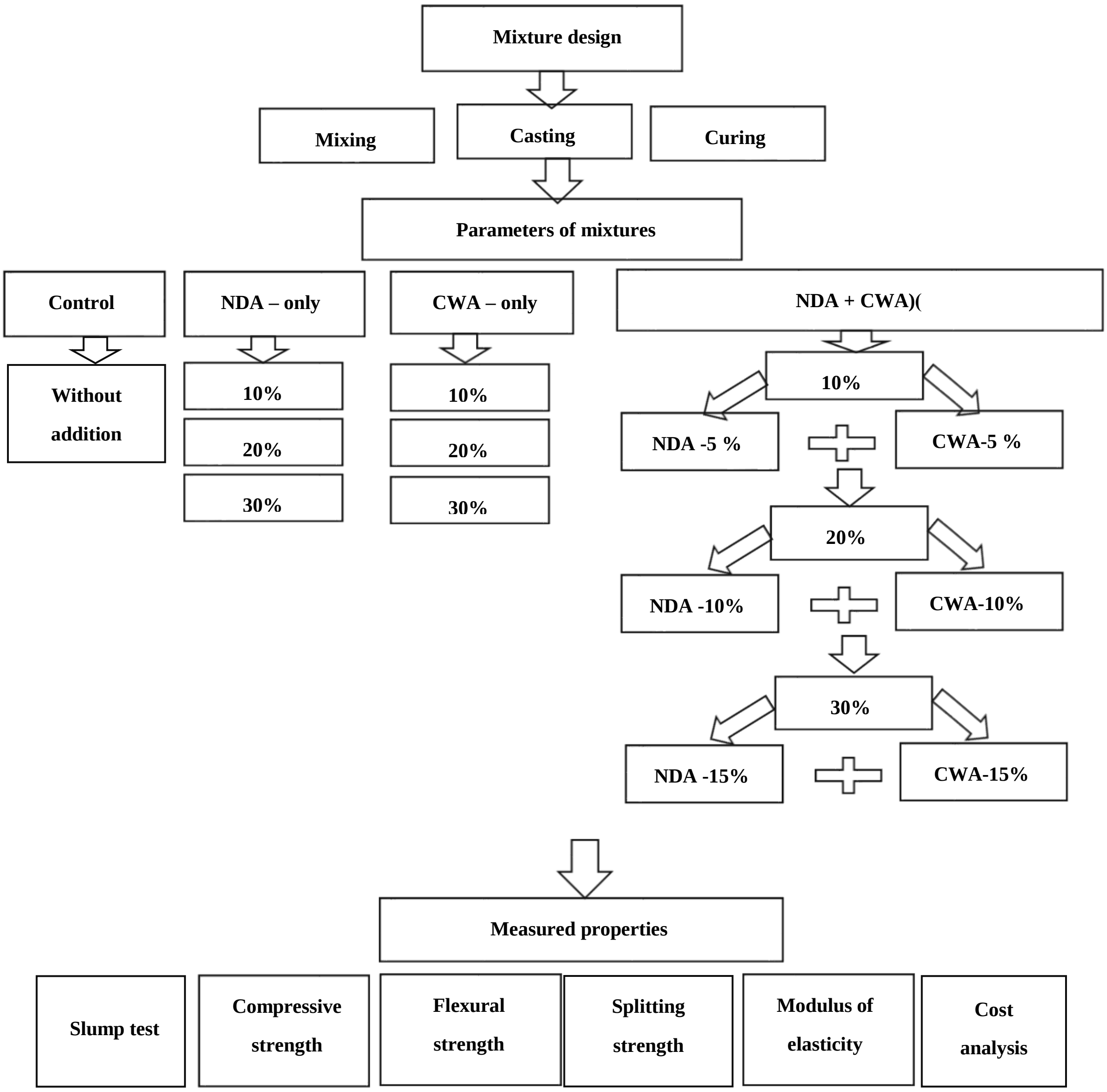


Fig. 1. Experimental program details of the carried out.

3.1. Material

The cement type utilized was CEM I 42.5 N, and the Helwan cement was made in compliance with BS EN 197-1 [26]. The experiment employed the Egyptian brand Portland cement, adhering to the specifications provided by a ready-mix concrete company. To guarantee the excellence of the concrete, it was crucial to consider the stability of the Portland cement and refrain from acquiring aged or moist cement. In regards to the aggregates, the fine aggregate consisted of natural coarse aggregate that had been sifted through a sieve with a 4.76 mm aperture size, also known as sieve no. 4.

The elongation index, reported as a percentage, was calculated for the natural aggregates, as well as for the natural aggregate, NDA, and CWA. The elongation index values for natural aggregates, NDA, and CWA were 12.5%, 16.3%, and 14.2%, respectively, as depicted in **Fig. 3**.

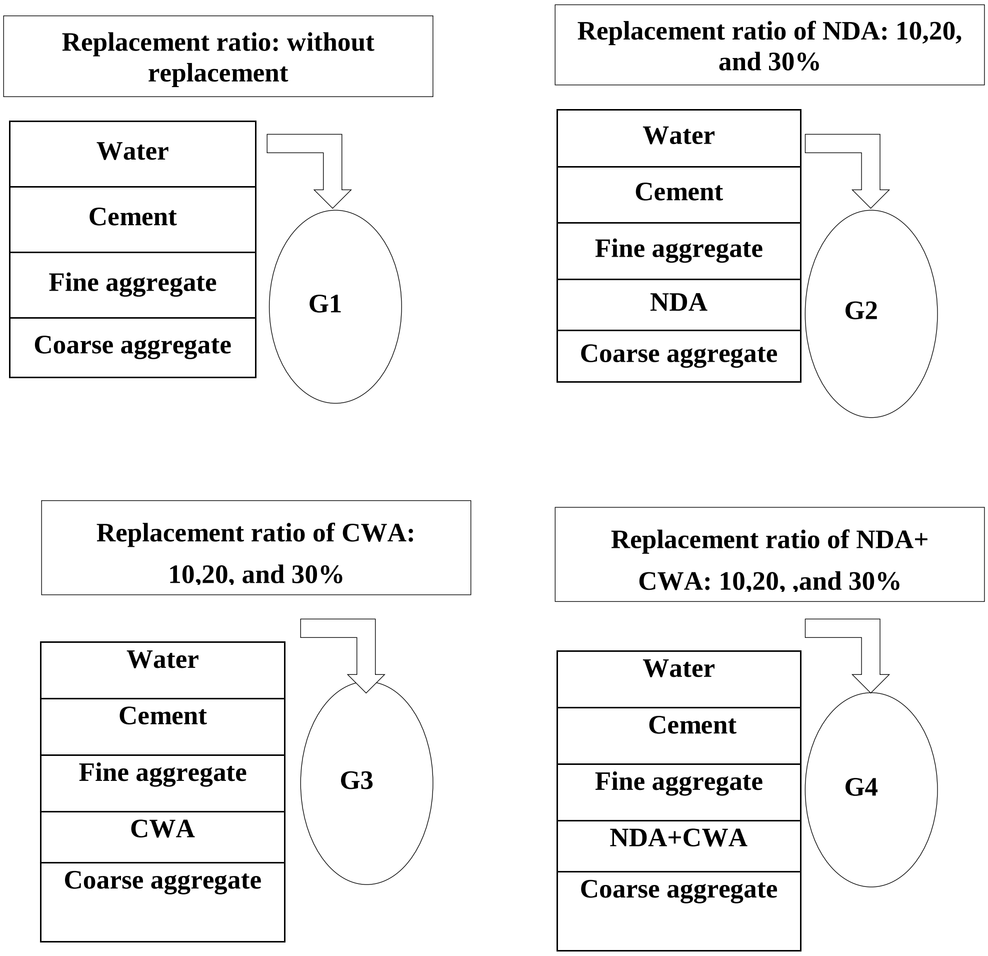


Fig. 2. Mixtures components of NDA and CWA in concrete.

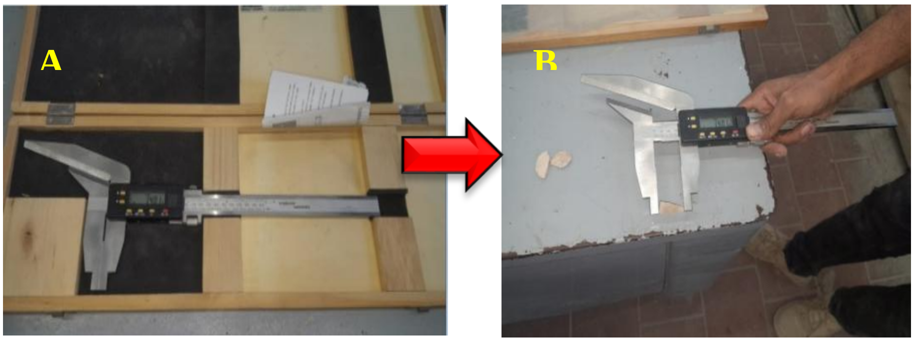


Fig. 3. A) measurement of elongation index, and B) measurement of elongation index with sample.

As per BS EN 196-1, the fine aggregates have a fineness modulus ranging from 3.2 to 3.1. The fineness modulus mustn't differ from the standard by more than 0.2, as stated in the reference (BSI 2005) [27]. The screening examination results indicated that the sand's fineness fell within the specified range, and the water met the British Standard, BS EN 1008 (EN 2002) [28]. To improve the characteristics of SHPC, NDA and CWA were added as natural coarse aggregates in proportions of 10%, 20%, and 30%. **Fig. 4** depicts the grain size distribution of NDA, CWA, and Natural Coarse Aggregate (NCG).

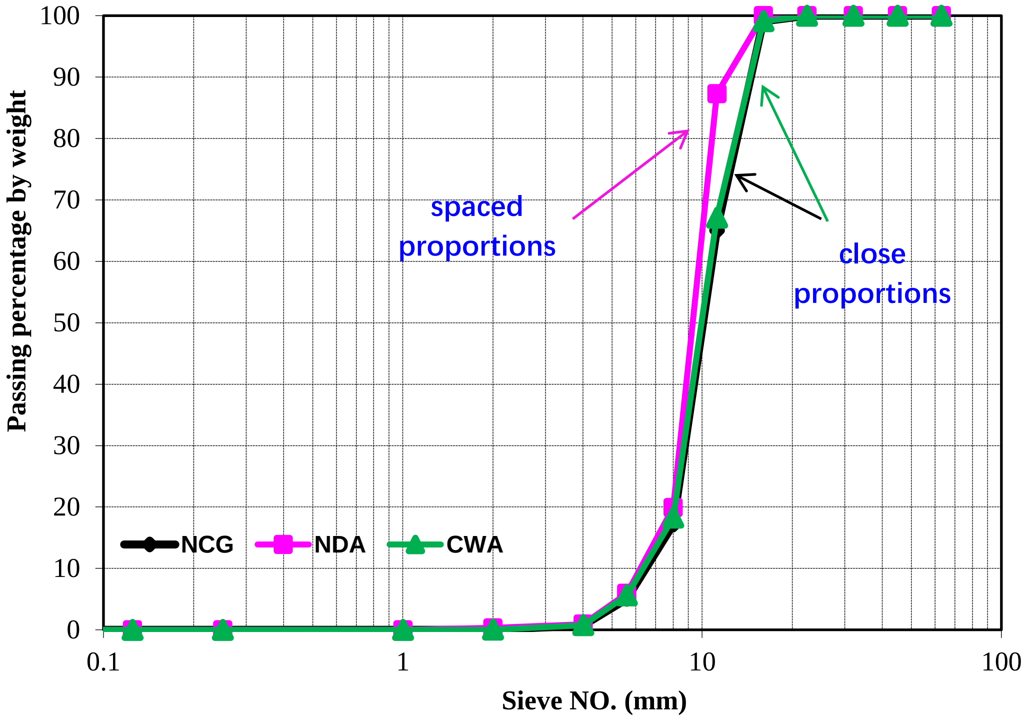


Fig. 4. The grain size distribution for NCG, NDA, and CWA.

3.2 Nucleus Dates Waste (NDA)

Egypt generates around 480,000 tons of nucleus dates trash annually, primarily during the palm growing season. The manufacturing process of NDA consists of three distinct phases. Initially, the date kernels are separated from the date crop. Furthermore, the kernels undergo a process of immersion in water for 24 hours, enabling them to absorb the water. Moreover, the contaminants adhering to the nucleus dates are eliminated. After that, the nucleus dates are subjected to a 24-hour sun-drying process until they reach a state of total dryness. **Fig. 5** presents a comprehensive outline of the complete process of creating nucleus dates aggregate. **Fig. 6** displays the constituents of the date fruit, emphasizing the elements that lead to the creation of the waste from the date's core.

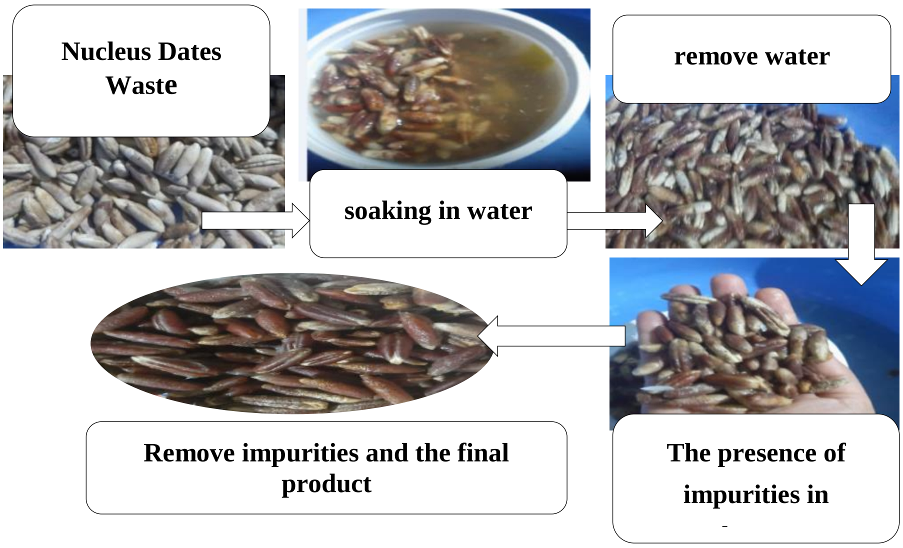


Fig. 5. Production process of nucleus dates waste.

3.3 Ceramic waste aggregate (CWA)

Egypt generates substantial ceramic trash, from 20,000 to 180,000 metric tons annually. The manufacturing of CWA typically comprises three stages: Initially, ceramic waste is gathered from manufacturers and produced as a secondary product. Additionally, the trash undergoes a process where it is fed into a jaw-crushing machine, facilitating the fragmentation of the waste into smaller fragments. Furthermore, the pulverized ceramic waste is further filtered using a sieve to acquire ceramic fractions with a size of 10 mm. This sieving procedure guarantees the desired particle size to use as aggregate. The outcome of these phases is the debris of ceramic waste, which can be employed as CWA. **Fig. 7** presents a comprehensive outline of the complete procedure for manufacturing ceramic waste aggregate. **Fig. 8** depicts the constituents of ceramic waste, emphasizing the elements that constitute the waste material produced by ceramic plants.

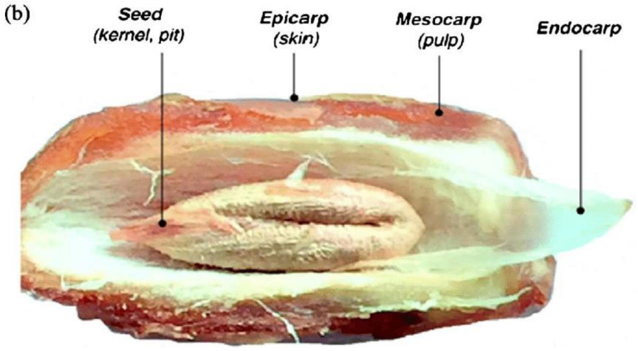


Fig. 6. Ingredients of the date fruit[29].

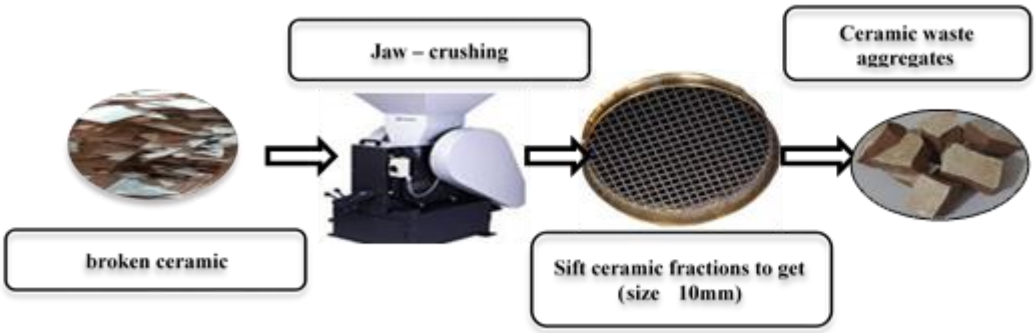


Fig. 7. Production process of ceramic waste.

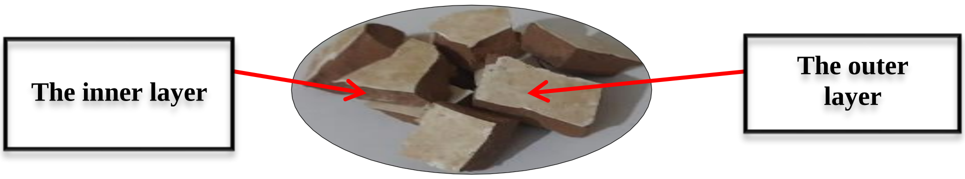


Fig. 8. Ingredients of ceramic waste.

3.4. Methods

This research aims to reduce the adverse environmental effects caused by agricultural and industrial waste, notably dates and ceramic materials, by finding ways to use and recycle them. The research intends to decrease the dependence on natural resources and mitigate their excessive utilization and depletion by utilizing NDA and CWA as replacements for natural coarse aggregates. The engineering properties of freshly mixed high-performance concrete were evaluated by inserting NDA and CWA at different ratios to determine the concrete's engineering qualities. The Assessment focused on feasibility and the desirable replacement rate, which consisted of cement, aggregates, and other additives as constituents of high-performance concrete. A high-performance super-plasticizer concrete admixture was utilized to minimize the water needed for mixing. This mixture, consisting of a water-based solution of a modified poly-carboxylate base (such as Viscocrete - 5930, which meets the standards of ASTM C494 Type G and F and BS EN 934 Part 2), helps to achieve the necessary ease of working and performance of the concrete mixes. The high-performance concrete was formulated by meticulously blending the components in accurate ratios and integrating a suitable quantity of water.

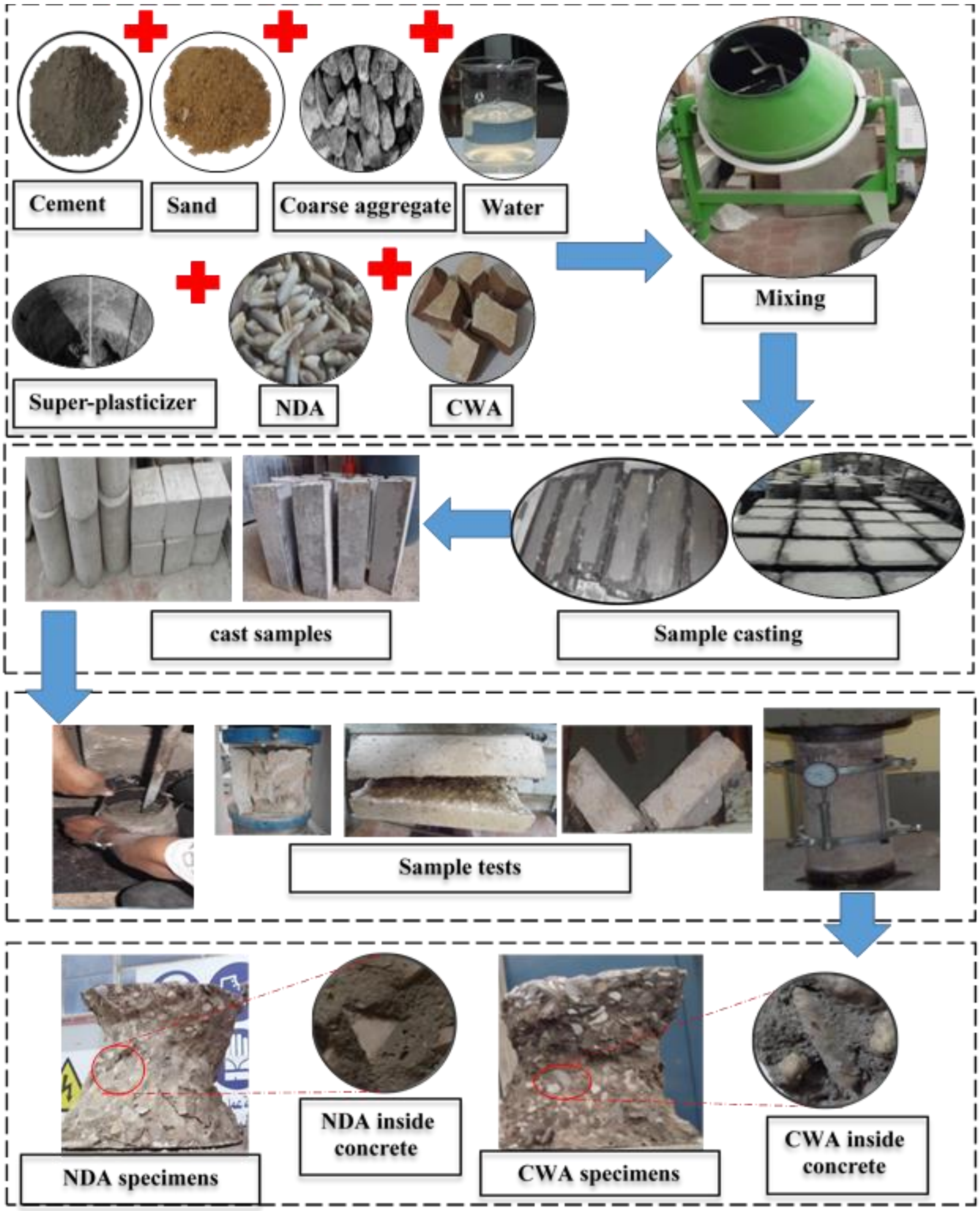


Fig. 9. Preparation of sustainable high-performance concrete (SHPC) specimens.

3.5 Preparation of concrete specimens

The composition of each of the adolescent SHPC mixes is provided in **Table 1**. The initial mixture served as the control, devoid of any utilization of industrial or agricultural waste. The remaining nine combinations formed the NDA, CWA, and NDA + CWA groups. Each of the three groups used ratios of 10%, 20%, and 30% for NDA, CWA, and NDA + CWA, respectively. The ratio of cement to water was maintained at a consistent level. The optimal preparation process was identified through multiple attempts using different mixing methods. Subsequently, water was introduced following the completion of the dry-mixing process. To achieve SHPC, a unique mixing process must be employed that guarantees the consistency of the mixture. The concrete mixtures were mechanically mixed according to the following procedure:

Combine cement, silica fume, and quartz powder in a pan mixer and stir for a minute together.

The pan mixer gradually receives half of the mixing water and continues mixing for another four minutes.

Mix the correct quantity of admixture with the remaining half amount of water and ultimately incorporate them in the last blend.

The fine aggregate should be added gradually, and after five minutes, the coarse aggregation should be done to achieve completeness; see **Fig. 4**.

Table 1. Mix proportion of NDA and CWA concrete for 1 m^3 (kg/m^3)

No	Mix ID	Cement	Silica fume	Q. P.	Natural Sand	Coarse Size 10 mm	NDA	CWA	NDA+ CWA	Water	S.P.	Water /binder ratio
1	C -0.0 %	550	110	316	632	632.0	0	0	0	161	23.1	0.244
2	NDA -10%	550	110	316	632	568.8	63.2	0	0	161	23.1	0.244
3	NDA -20%	550	110	316	632	505.6	126.4	0	0	161	23.1	0.244
4	NDA -30%	550	110	316	632	442.4	189.6	0	0	161	23.1	0.244
5	CWA-10%	550	110	316	632	568.8	0	63.2	0	161	23.1	0.244
6	CWA-20%	550	110	316	632	505.6	0	126.4	0	161	23.1	0.244
7	CWA -30%	550	110	316	632	442.4	0	189.6	0	161	23.1	0.244
8	NDA + CWA -10%	550	110	316	632	568.8	0	0	63.2	161	23.1	0.244
9	NDA + CWA -20%	550	110	316	632	505.6	0	0	126.4	161	23.1	0.244
10	NDA + CWA -30%	550	110	316	632	442.4	0	0	189.6	161	23.1	0.244

3.6 Testing procedure for sustainable high-performance concrete (SHPC)

Experiments were conducted to evaluate the toughened properties of SEC mixtures. **Table 2** displays SEC mixes' mechanical properties, including elastic modulus and compressive, tensile, and flexural strengths. Cubic samples measuring 100X100X100 mm underwent a compression test at 7, 28, and 91 days following Standard 1881 [30]. According to ASTM C496/C496M-17(2017)[31], A split tensile test was conducted on specimens with a diameter of 150 mm and a length of 300 mm after 91 days. As per the ASTM C78/C78M-18 standard [32](Concrete and Aggregates 2010), A flexural test was performed on prism samples of 100 mm x 100 mm x 500 mm after 91 days. As to the ASTM C469/C469M-14(2002) standard [33], The elastic modulus of cylinder specimens, measuring 100 mm in diameter and 200 mm in length, was determined after 91 days.

Table 2. Mechanical Properties of the NDA and CWA Concrete

No	Mix ID	Slump test (mm)	Compressive strength (MPa) at seven days	Compressive strength (MPa) at 28 days	Compressive strength (MPa) at 91 days	Flexural strength (MPa) at 91 days	Splitting strength (MPa) at 91 days	Modulus of elasticity (MPa) at 91 days
1	C -0.0 %	75	48.4	80.2	93.4	10.7	10.2	48010
2	NDA -10%	79	50.5	81.4	93.6	10.9	10.4	48230
3	NDA -20%	80	44.6	76.8	91.2	10.1	9.75	47003
4	NDA -30%	81	40.7	68.1	79.3	8.6	8.15	46799
5	CWA-10%	71	45.8	77.2	91.6	10.3	9.86	47823
6	CWA-20%	68	42.1	73.4	88.2	9.7	9.31	46825
7	CWA -30%	65	37.8	60.1	69.2	7.3	7.01	42987
8	NDA + CWA -10%	76	46.7	79.5	93.2	10.5	10.1	48002
9	NDA + CWA -20%	73	43.6	75.5	90.5	10	9.65	46927
10	NDA + CWA -30%	71	39.3	65.7	75.2	8.0	7.66	45827

4. Results and discussion

Performance tests were conducted on recently mixed concrete to assess the Influence of replacing the aggregates with one or both components on the engineering properties of concrete. The specific test results are displayed in **Table 2**.

4.1 Slump test

Fig. 10 and **Fig.** 11 depict the impact of replacing a portion of SHPC with NDA or CWA on the slump value. To obtain a thorough dispersion and enhance the ease of handling, it is essential to incorporate a super-plasticizer, such as S.F. (supposedly a particular type of super-plasticizer), into SHPC mixes that contain pozzolanic exemplary components[12, 34]. Using S.F. enhances the fluidity or slump of the SHPC combinations. Compared with S.F., including NDA or CWA provides enhanced uniformity for the intended blending ratios. Incorporating NDA at a proportion of 30% in the final concrete mix led to the lowest slump value, which signifies a reduction in workability.

Conversely, the mixture including CWA with a replacement fraction of 30% had a marginally higher slump value of 65 mm, suggesting improved workability or flowability. The slump value is a quantitative indicator indicating concrete's consistency and workability [35, 36]. A more excellent droop value signifies a more dense and malleable mixture, whereas a lower slump value implies a more rigid or less malleable mixture. These data indicate that adding NDA or CWA, especially at higher replacement levels, can affect the slump value or workability of the SHPC combinations. The precise ratios and qualities of the aggregates, along with the inclusion of S.F., influence the slump values and workability of the concrete mixtures. [37-40].

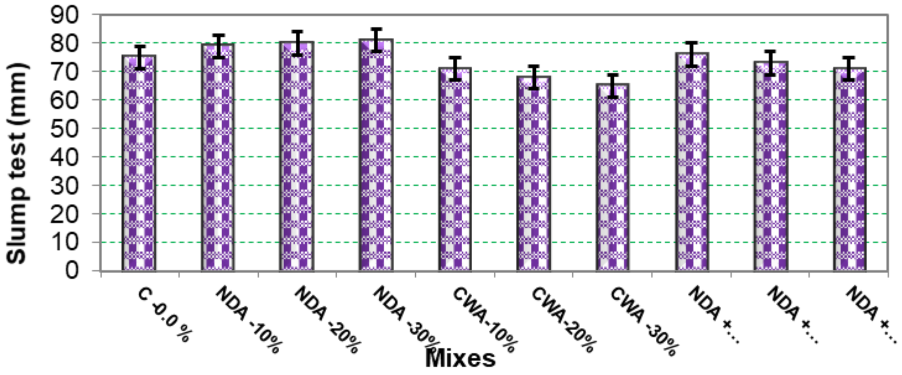


Fig. 10. Standard deviations for slump test of NDA and CWA.

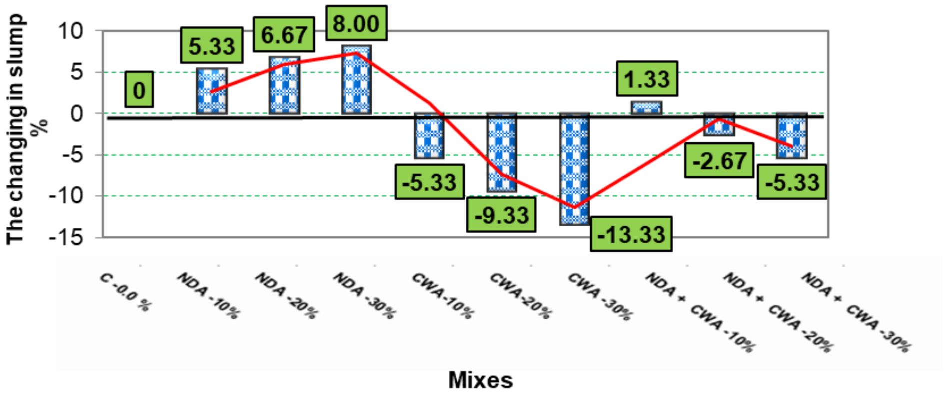


Fig. 11. Change in slump test (%) of NDA and CWA.

4.2 Influences of SCPS and PGS on compressive strength for sustainable high-performance concrete

Fig. 12 shows that the SHPC created has a compressive strength at 91 days, which meets the requirements for structural grade. All replacement ratios (NDA, CWA, and NDA+CWA) have equal replacement ratios. However, substituting 10% by volume of gravel for NDA resulted in only a slight increase in compressive strength of 0.21%. **Fig. 13** illustrates that the compressive strength of SHPC at 91 days was reduced by 2.36% and 15.10% when natural gravel was replaced with 20% and 30% NDA, respectively. Similarly, when the highest amount of natural sand was substituted with CWA (varying from 10% to 30% replacement), the compressive strength of SHPC fell by 1.93% to 25.91%. The results suggest that substituting natural sand with NDA (up to 10%) increases strength, but a higher replacement ratio results in a more significant decrease in strength. The Use of NDA in SHPC is expected to enhance its compressive strength compared to CWA, possibly due to disparities in their physical properties [41, 42]. Ultimately, the combination of NDA+ CWA effectively reduces the rate of strength decline, reaching a drop of 19.49% when 30% of SCPS+PGS is used as a replacement. According to **Fig. 12**, the decrease continued until a 30% substitution was reached [43, 44]. The increase in the replacement ratio of natural gravel aggregates with waste coarse aggregates corresponds to the decrease in compressive strength in the current experiment. **Fig. 12** displays the standard deviations for the compressive strength of NDA and CWA.

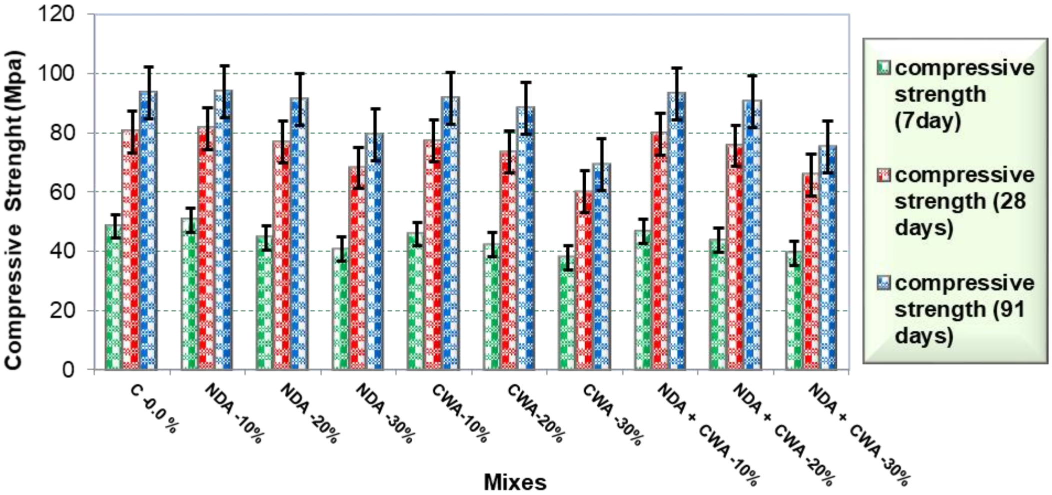
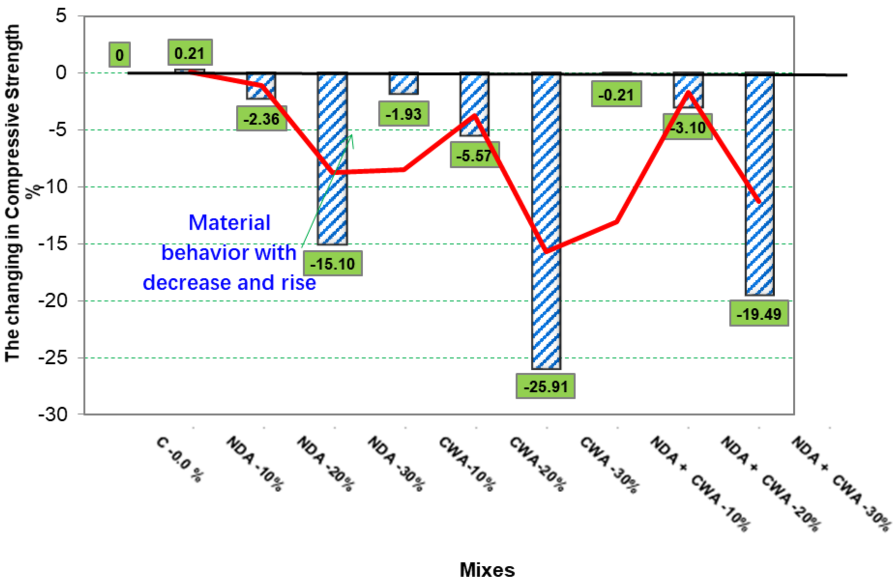


Fig. 12. Standard deviations for compressive strength of NDA and CWA.



Material behavior with decrease and rise

Fig. 13. Changing in compressive strength (%) of NDA and CWA at 91 days.

The findings suggest that incorporating NDA and CWA into the concrete mixture reduces the number of pores or voids and promotes the development of a well-defined interfacial zone in the constructed samples. These compounds enhance the density and strength of the concrete structure. The concrete's outstanding performance, seen after 91 days, indicates that even small porous areas with low replacement ratios successfully improve the link between the paste and particles, leading to a more robust concrete structure[45, 46]. Nevertheless, as NDA and CWA substitution rates rise, there is a proportional augmentation in voids and a deterioration of the concrete structure. It is essential to balance using these aggregates for sustainable purposes and preserving the required strength and structural integrity. The exceptional performance of the concrete at 91 days corresponds to the performance seen in concrete samples at 7 and 28 days [47, 48]. Incorporating NDA and CWA enhances the compressive power of concrete[49, 50].

4.3 Influences of NDA and CWA on flexural strength for sustainable high-performance concrete

Fig. 14 shows that replacing 10%, 20%, and 30% of NDA with natural gravel in SHPC decreases flexural strength after 91 days. When the NDA is replaced with a volume of 30%, the flexural strength decreases by 5.61%, substituting natural gravel with CWA at a volume replacement rate of 30% results in a reduction of 9.35% in flexural strength[49, 50]. It is essential to mention that, like compressive strength, a slight decrease in flexural strength is noticed when the replacement ratio reaches 10%. When the amount of gravel is substituted with NDA, CWA, or NDA+CWA by more than 30%, the flexural strength drops by 19.63%, 31.78%, and 25.23%, respectively, compared to the control flexural strength. This information is illustrated in **Fig. 15**. These findings align with references, suggesting that the decrease in flexural strength percentage when substituting natural gravel aggregates with NDA, CWA, or NDA+CWA is comparable to earlier research [51-53]. The quantity or composition of coarse particles has minimal Influence on the F/C ratio. Nevertheless, the flexural test findings of the SEC indicated that including aggregates (NDA or CWA) significantly diminished the structural integrity of the prisms [28, 30]. **Fig. 14** displays the standard deviations for the compressive strength of NDA and CWA.

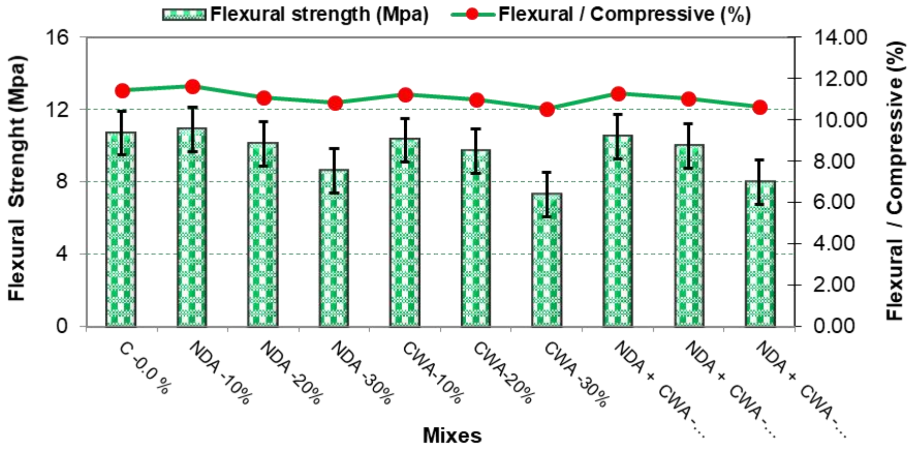


Fig. 14. Standard deviations for flexural strength (MPa) and flexural/compressive (%) at 91 days.

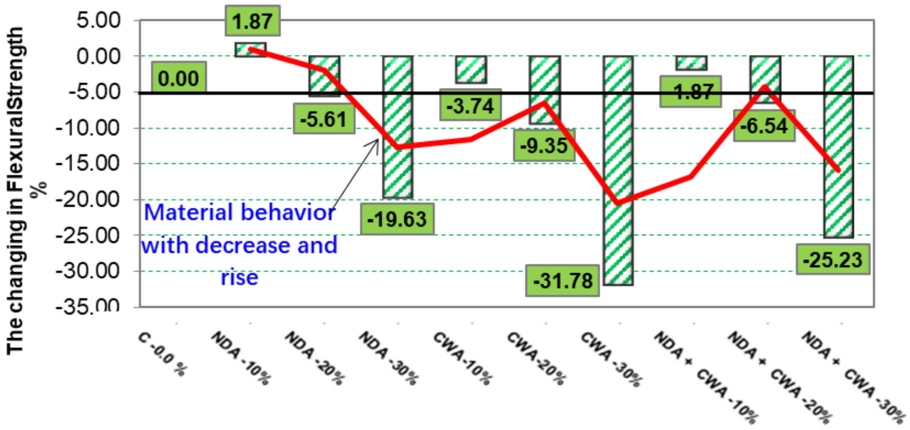


Fig. 15. Change in flexural strength (%) of NDA and CWA.

4.3.1 Relationship between compressive strength and flexural strength

This section explores the relationship between the compressive strength and flexural strength of SHPC. **Fig. 16** illustrates this correlation, and the line that most accurately represents the correlation is as follows:

$$Y=0.1388X-2.4035 \tag{1}$$

where X is the compressive strength of the cube (MPa), and Y is the flexural strength of the cube (MPa). The R2 value, which gauges the accuracy of the equation, is reasonably relatively high at 0.9854.

Fig. 16 illustrates the correlation between the compressive and flexural strength of the specimens in the SHPC mixtures, as indicated by the information. **Fig. 16** reveals that all concrete mixtures' compressive and flexural strengths correlate well. A line from **Fig. 16** represents the best-fit line for the relationship between compressive and flexural strengths, with very few fluctuations or deviations. It shows that compressive strength is related to the flexural strength of concrete; this implies that, based on the linear regression analysis, higher compressive strength may lead to higher flexural strength.

The coefficient of determination (R^2) is a statistical measure used to determine how accurate it is to predict compression strengths based on flexure values of specimens. A larger R^2 signifies a stronger correlation between two variables; hence, the tensile modulus can sometimes be used to reliably predict concrete's compressive modulus since it gives more significant figures than others. The findings presented indicate that there is a positive relationship between the tensile and compressive strength of concrete.

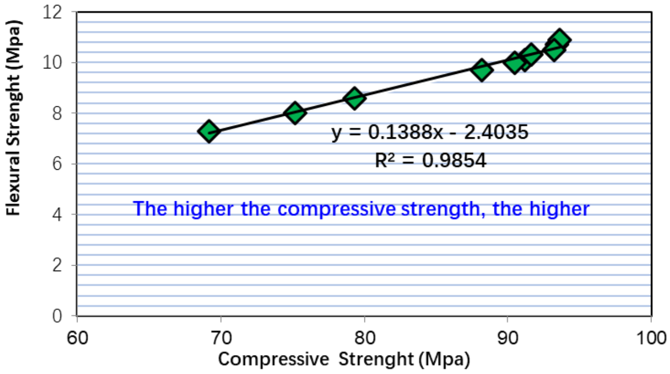


Fig. 16. Correlation between flexural strength and compressive strength at 91 days.

4.4 Influences of NDA and CWA on Splitting Strength for Sustainable High-performance Concrete (SHPC)

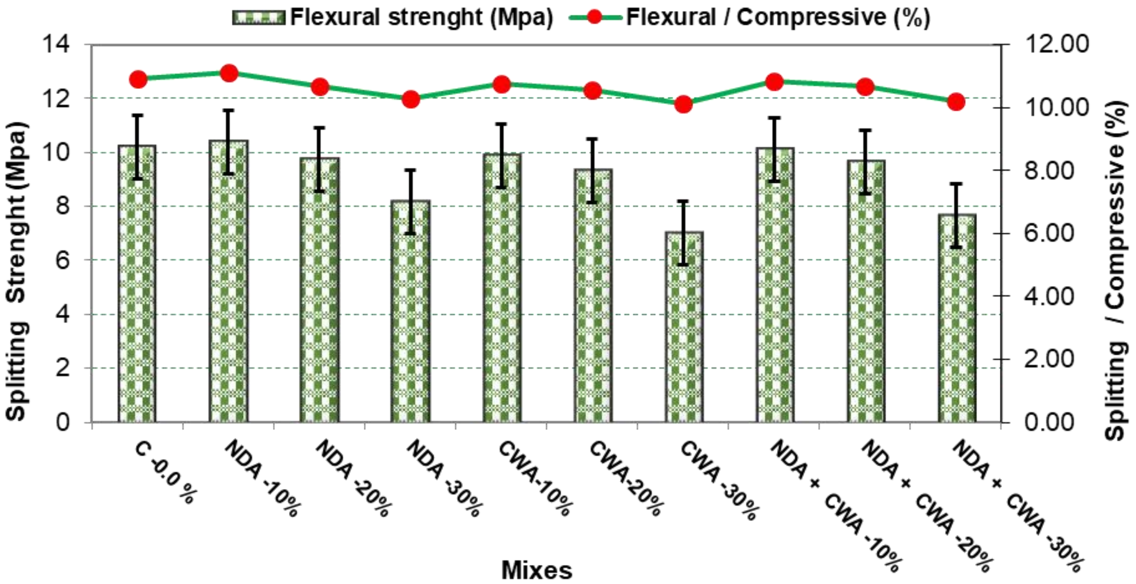


Fig. 17. Standard deviations for splitting strength (MPa) and Splitting /compressive (%) at 91 days.

Fig. 17 and **Fig. 18** illustrate the decrease in Splitting strength after 91 days for SHPC after replacing 10% to 30% of natural gravel with NDA, CWA, and NDA+CWA. The most significant decrease is observed when substituting 30% of the volume with NDA, leading to a 19.63% loss in Splitting strength. Similarly, after replacing 30% of the sand volume with CWA, there is a decrease in Splitting strength of 31.78%[54, 55], and replacing 30% of the native sand with NDA+CWA results in a drop in Splitting strength of 25.23%. Similar to the findings on compressive strength, there is a minor decrease in Splitting strength when sand is substituted up to a proportion of 10%. When the sand volume is substituted with NDA, CWA, or NDA+CWA by more than 20%, the Splitting strength drops by 5.61%, 9.35%, and 6.54%, respectively, compared to the control Splitting strength. The decrease in Splitting strength caused by substituting natural coarse aggregates with NDA, CWA, and NDA+CWA is comparable to the results published by Raval et al. and Siddique et al.[56, 57]. The amount or type of coarse aggregates has almost no impact on the S/C ratio. However, the Splitting test of the SHPC showed that aggregates (NDA or CWA) reduced the failure behavior of prisms. [28, 30]. **Fig. 17** shows Standard deviations for the Splitting strength of NDA and CWA.

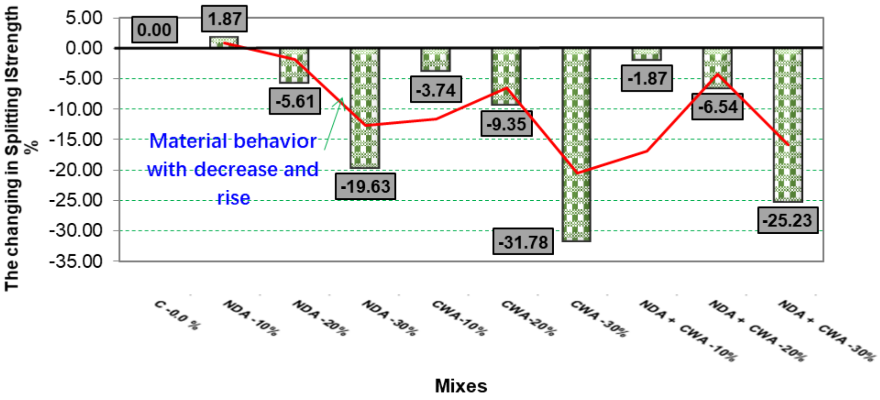


Fig. 18. Change in flexural strength (%) of NDA and CWA.

4.4.1 Relationship between compressive strength and splitting strength

This section explores the relationship between the compressive strength and splitting strength of SHPC. **Fig. 19** depicts the correlation, and the line that most accurately represents the correlation is as follows:

$$Y=0.1339X-2.3807 \tag{2}$$

where X is the cube compressive strength (MPa), and Y is the cube flexural strength (MPa). The R^2 value, which assesses the equation's accuracy, is reasonably high at 0.9904.

The correlation between the compressive strength and splitting strength of the specimens is illustrated in **Fig. 19**. The connection is inferred for all specific mixtures, considering the extensive array of outcomes from different combinations. The data presented in **Fig. 19** demonstrate that the line fit exhibits a more robust correlation and fewer fluctuations. The value of R^2 indicates the extent to which the compressive strengths of specimens may be accurately predicted using their splitting strengths. The deduction is that when the compressive strength of concrete increases, the splitting strength of concrete also increases.

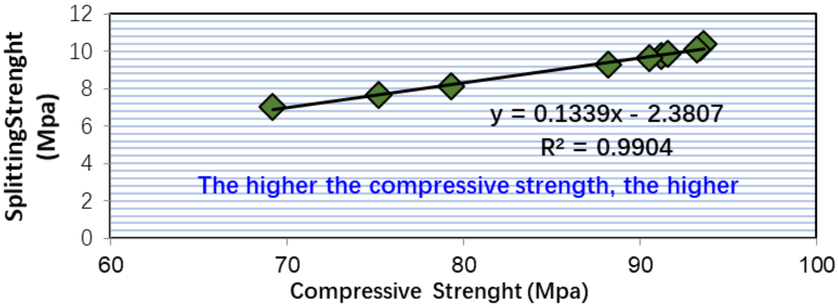


Fig. 19. Correlation between flexural strength and compressive strength at 91 days.

4.5 Modulus of elasticity for sustainable high-performance concrete

To assess the deformation characteristics of SHPC containing NDA and CWA, the modulus of elasticity was measured and compared to the control mixture. **Fig. 20** demonstrates that the modulus of elasticity for SHPC with NDA and CWA has a comparable upward trend when the replacement ratio is 10%. However, once the ratio goes beyond this point, the modulus of elasticity begins to decline. It reaches its maximum reduction of 10.46% for the NDA+CWA mixture when the replacement ratio is 30% (**Fig. 21**). The decrease in modulus of elasticity can be attributable to the variations in the coefficient of flatness and stickiness among the NDA, CWA, and normal aggregates employed in the control mix. The differences in the form and surface properties of the alternate aggregates can impact the bonding between the aggregates and the concrete matrix, resulting in a reduction in the modulus of elasticity.[53, 58, 59] The low modulus of elasticity reported in SHPC combinations with variable NDA and CWA can be explained by the structural features of these alternative aggregates. The variation in the composition of NDA and CWA is believed to be the reason for the restricted impact on the modulus of elasticity [60-62]. The compressive strength of Group I mixes, which have a 10% substitution of NDA, is greater than that of Group II mixes with CWA.

Consequently, Group I mixes demonstrate an excellent elasticity modulus [60, 63, 64]. **Fig.** 20 illustrates the standard deviations for the compressive strength of NDA and CWA. The standard deviations offer insights into the dispersion and uniformity of the compressive strength measurements obtained for these aggregates. One can evaluate the dependability and consistency of the experimental results by examining the standard deviations.

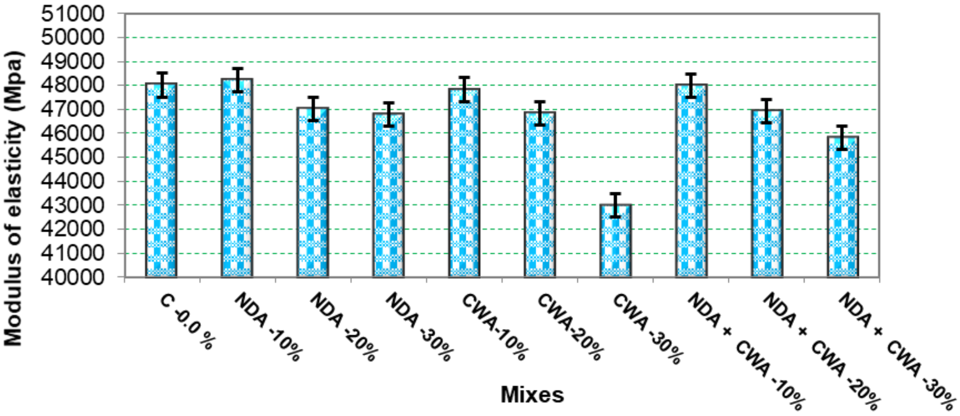


Fig. 20. Standard deviations for modulus of elasticity of all mixtures at 91 days.

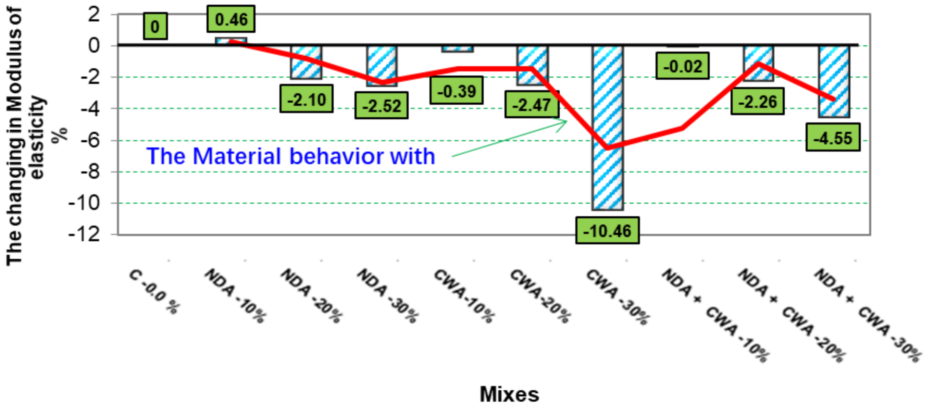


Fig. 21. Change in Modulus of elasticity (%) of NDA and CWA.

4.6 Cost analysis for sustainable high-performance concrete

Table 3 presents a comparative analysis of the estimated expenses for each examined combination in this research. An important point is that NDA and CWA are not readily available in the local market since they are non-recyclable in Egypt. Currently, they are being disposed of in landfills. The costs considered for each combination encompass the costs associated with blending water, cement, silica fume, quarry goods, natural sand, coarse aggregate, and super-plasticizer (S.P.). The unit values were determined according to the prevailing pricing in the Egyptian local market when the raw materials were purchased for the research, which was carried out until December 2022. Based on the cost study, the price of each mix varied between USD 194.064 and 190.344 per cubic meter (M3). The combinations containing NDA-10%, CWA-10%, and NDA+CWA-10% had the highest cost, measuring 0.74% lower than the control mix, as anticipated. The cost had a linear relationship with the dosage of NDA, increasing up to 30% [65-67]. It is important to mention that the cost of the NDA and CWA combinations, particularly those substituted by a mild dosage of 10%, was the same as the control mix. The cost variance for the mixtures that included NDA and CWA ranged from 0% to 1.92%, depending on the dosage. The combination's dosage varied from 10% to 30% [58, 68, 69].

Table 3. Cost analysis of all mixtures for (per m^3) ($)

No	Mix ID	Cement	Silica fume	Q. P.	Natural Sand	Coarse	NDA	CWA	NDA + CWA	Water	S.P.	Total Cost ($)	Cost increment (compared to control)
1	C -0.0 %	33	88	50.56	10.11	12.39	0	0	0	0.004	20	194.064	100
2	NDA -10%	33	88	50.56	10.11	11.15	free	0	0	0.004	20	192.824	99.36
3	NDA -20%	33	88	50.56	10.11	9.91	free	0	0	0.004	20	191.584	98.72
4	NDA -30%	33	88	50.56	10.11	8.67	free	0	0	0.004	20	190.344	98.08
5	CWA-10%	33	88	50.56	10.11	11.15	0	free	0	0.004	20	192.824	99.36
6	CWA-20%	33	88	50.56	10.11	9.91	0	free	0	0.004	20	191.584	98.72
7	CWA -30%	33	88	50.56	10.11	8.67	0	free	0	0.004	20	190.344	98.08
8	NDA + CWA -10%	33	88	50.56	10.11	11.15	0	0	free	0.004	20	192.824	99.36
9	NDA + CWA -20%	33	88	50.56	10.11	9.91	0	0	free	0.004	20	191.584	98.72
10	NDA + CWA -30%	33	88	50.56	10.11	8.67	0	0	free	0.004	20	190.344	98.08

5. Conclusion

The study examined the possible enhancement of sustainable high-performance concrete (SHPC) by using ceramic waste as coarse aggregates and substituting extra cementation materials for cement. The study also sought to evaluate the environmental sustainability and structural resilience of utilizing such materials in buildings. The study's findings allow for the following specific conclusions to be made:

The inclusion of S.F. enhances the fluidity of SHPC. Compared to S.F., it provides significantly enhanced uniformity for the intended blending ratios. Adding NDA -30% resulted in the lowest slump value in the final concrete mix. Conversely, the mix with CWA -30% recorded a slightly higher landing value of 65 mm.

The material's compressive strength rose when natural sand was replaced (up to 10% for NDA). Still, there was a more significant loss of compressive strength when a high replacement ratio was seen as a result of the variations in the physical properties of each substance.

When the ratio of natural gravel aggregates is substituted with NDA, CWA, or NDA+ CWA, the decrease in flexural strength is comparable to the reductions observed in compressive strength.

When most gravel is replaced with NDA, there is a reduction of 19.63%, equivalent to replacing 30% of the volume. Similarly, when most of the sand is replaced with CWA, Splitting strength is reduced by 31.78%, comparable to replacing 30% of the volume.

The modulus of elasticity of SHPC with NDA and CWA shows a consistent increase at a replacement level of 10%. However, beyond this point, the modulus of elasticity declines by approximately 10.46% until it reaches its maximum value at a ratio of NDA+CWA-30% for the II mixture.

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CRediT authorship contribution statement

All authors contributed equally to conduct this research.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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