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ORIGINAL ARTICLE

Utilization of Cement Kiln Dust and Aluminum Powder as Partial Cement Replacement in Sustainable High-Performance Concrete

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Abstract: This research presents a procedure for further evaluation of the Effect of incorporating cement kiln dust (CKD) and aluminum powder (AP) on the mechanical features of the concrete. CKD and AW were converted into powder materials and used as a partial substitution of cement in concrete mixes at 0%, 10%, 15%, and 20% proportions. The properties focused on included the fresh and hardened characteristics of the concrete. Utilization of the slump test allowed the assessment of the workability of the fresh mixes, and after 28 days of curing, the hardened properties to be evaluated included compressive strength, flexural strength, splitting strength, and dry shrinkage. The replacement of the control, including a reduction in the level of CKD and AP replacement materials up to 10% has been shown to enhance the improvement of structural mechanical properties of concrete. Similarly, progressive replacement levels of 15% and 20% improved these properties slightly. Replacement of 10% resulted in a 22.92% increase in compressive strength of the specimen as opposed to 0% replacement specimens (Control), and this increase was observed in the rest of the mechanical properties as well. Besides, the incorporation of material replacement additives helped reduce shrinkage. The results of this study favour the formulation of "green" concrete with improved mechanical properties and reduced environmental impact in the building construction industry.

Keywords: Sustainable high-performance concrete (SHPC), cement Kiln Dust (CKD), aluminum powder (AP), mechanical properties.

1 Introduction

High-Performance Concrete, or HPC, is a generation of cementitious materials that could improve the construction industry's future. Since the volume of concrete and other construction materials may be reduced because of its excellent mechanical characteristics, durability means that the life span of a concrete structure can be prolonged. At the same time, maintenance activity is minimized, which is essential in nations with extreme weather conditions [1-3]. Usually, an HPC mixture consists of a combined optimized sharp aggregate with a high packing density, a low water-to-cement ratio, and the use of super-plasticizer required to achieve the necessary flow ability [4, 5]. The HPC type has a very low capillary porosity, which makes it resistant to penetration by destructive agents like chlorides and sulfates [6, 7]. Moreover, there is quite a good dispersion of fine aggregates with a maximum diameter of a few millimeters, with approximately 50% of cement paste used in the HPC mixture. This way, many commercialized HPCs use cement content that ranges at very high levels, which results in high embodied carbon content and its associated effects [8, 9]. Driven largely by function and market demand, the levels of the cement content in some HPC

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mixtures exceed those necessary for the economic sustainability of society. In this regard, the most recent research efforts all over the world have focused on ecological HPC owing to an enhancement of the matrix in which certain mineral fillers, i.e., limestone, rice husk, fly ash, metakaolin, glass powder, Aluminum powder, and waste granite powder, are used. It is clear how to consistently achieve ecological HPC by reducing the proportion of cement and silica fume [9, 10]. Some ecological HPC substitutes more than 20 wt% of such cement for SCM/Fillers while keeping a minimum amount of silica fume. The world's consumption of aluminium extracts has been high, reaching above 60 million tonnes yearly. The first producer is China with 37 million tonnes, with India, Russia, and Canada in the second, Egypt, and the Middle East [11-13]. Raw refining techniques deployed during the extraction of aluminum create approximately two to two and a half tons of solid waste against every ton of aluminum manufactured. This consists of a little waste rock, cement kiln dust, a little waste, and lots of other scraps and solid waste. One emerging industrial and environmental waste related to the Aluminium industry is spent pot lining (SPL) [14, 15]. SPL is the main solid waste in smelting processes and the second source of solid waste in the aluminium industry after bauxite residues. The effects of replacing portions of cement in concrete with Aluminium powder up to 50%. On the analysis, a 15% ratio was the optimal performance proclamation because of the low permeation properties attributable to the pozzolanic Effect of AP particles [16, 17]. Cement replacement of 20% with AP was advantageous to the hardened composite due to the filling of voids and supplementary binding phases developed. Within the last decades, several researchers have established that fine dust such as AP can replace HPC at up to 25 [18-20].

It noted that up to 30% substitution of HPC by AP was associated with loss of compressive strength when more than 15% replacement was attempted, since there were several reasons, such as the dilution effect of the benign phases of the HPC that contributed to binder action and the loss of CaO in the matrix. On the other hand, in general, nearly 80% of the building elements in Egypt use Cement Kiln Dust, and due to this fact, the fractional wastes resulting from their Utilization are large in amounts and make up about 4% of the total waste report [21-23]. The powder of cement kiln dust is an alumino-silicate with a high content of mullite and hematite. As a result, the possibility of recycling such wastes as cementitious material was investigated to address the issue of landfilling such wastes [24, 25]. Most of the fine CKD residues are of very high pozzolanic ability, leading to positive outcomes in the return of microporosity, morphology, mechanical properties, and durability [26, 27]. It made additional remarks to the previous studies that up to 5% CKD can be used as a substitute for the cement in concrete and observed higher mechanical and physical properties because of the pozzolanic action of the CKD particles, which filled the internal voids and enhanced the cement matrix.

However, for higher replacement percentages, even up to 15 %, mechanical properties have been reported to fall since the 'CH' content, which is needed for the pozzolanic reaction that bonds together the cementitious/active particles, lowers [5, 28]. When the w/C ratio was 0.50, The compressive strength at 28 days decreased by 1.8% and 4.5% when the CKD levels were 5% and 10%, respectively, When the w/C ratio was 0.60, the 28-day strength declined by 12.4% and 18% for the 5% and 10% substitutions, while at w/C ratio was 0.70, the declines were 8% and 13%, respectively. Additionally, mixtures with the 5% CKD content exhibited compressive strength values nearly matching those of the control mix, particularly at the water-to-binder ratio of 0.50. It concluded that when the water content drops below a ratio of 0.5, it will cause increased resistance compared to the control [20, 22, 28]. On the other hand, at constant water-to-binder ratios of 0.50, the compressive strength at 7 and 28 days increased by 1.8% and 2.6%, incorporating 5% and 10% AP, respectively. Increasing the ratio to 15 % AP led to a slight increase of 1.4% and 2.1% under the same AP levels, while at a ratio of 20% AP, strength losses of 8% and 13% were observed [5, 26, 28].

The present Investigation stands apart from earlier studies in a way that demonstrates a new method of waste utilization - this time transforming it into materials and later investigating the use of such materials in concrete construction. This research intends to tackle waste management problems, investigate sustainable materials, and thus go a step further in making the construction industry environmentally friendly. In this study, Cement Kiln Dust (CKD) and aluminum powder (AP) were incorporated into concrete in comparison with control concrete at the same ratio of water/cement to enhance compressive and flexural load abilities. The participation of materials improved the hydration process, thereby improving the mechanical properties. In conclusion, this research presents the impact of industrial waste materials as partial adhesives in formulating environmentally acceptable construction materials. This paper presents the possibility of being sustainable in concrete production using waste materials like CKD and AP, hence controlling the greenhouse effect.

2 Research Importance

Cement is usually required in large volumes in the high-strength concrete mixes; this is lessened when AP and CKD materials are employed as partial cement substitutes. This substitution tends to enhance the durability of the HS concrete since cement, which presents durability and produces too significant carbon emissions, is less utilized. The Utilization of AP and CKD materials to create green concrete also depends on the rational use of industrial waste. The study aims to promote sustainable construction by using waste materials such as cement and addressing the construction waste problem. And this is illustrated more through the following points.

This study aims to undertake a detailed survey of AP and CKD to bridge the gap that has been yawning in previous studies.

In the production of green concrete, AP and CKD are used as chemical admixtures to decrease the overall amount of cement required.

Different AP and CKD ratios in the manufacturing of green concrete yield good compressive strength.

Zero effluents were used during Fabrication, and green concrete's new features and mechanical properties were also used.

The nature of the work makes it possible to go deeper into AP and CKD and avail themselves of many studies.

After conducting previous studies, researchers could not find mixtures or efficient combinations of both materials in concrete. Therefore, the ideal mixes for each material, individually or in combination, were determined as novel work in the paper.

3 Experimental Work

3.1 Materials

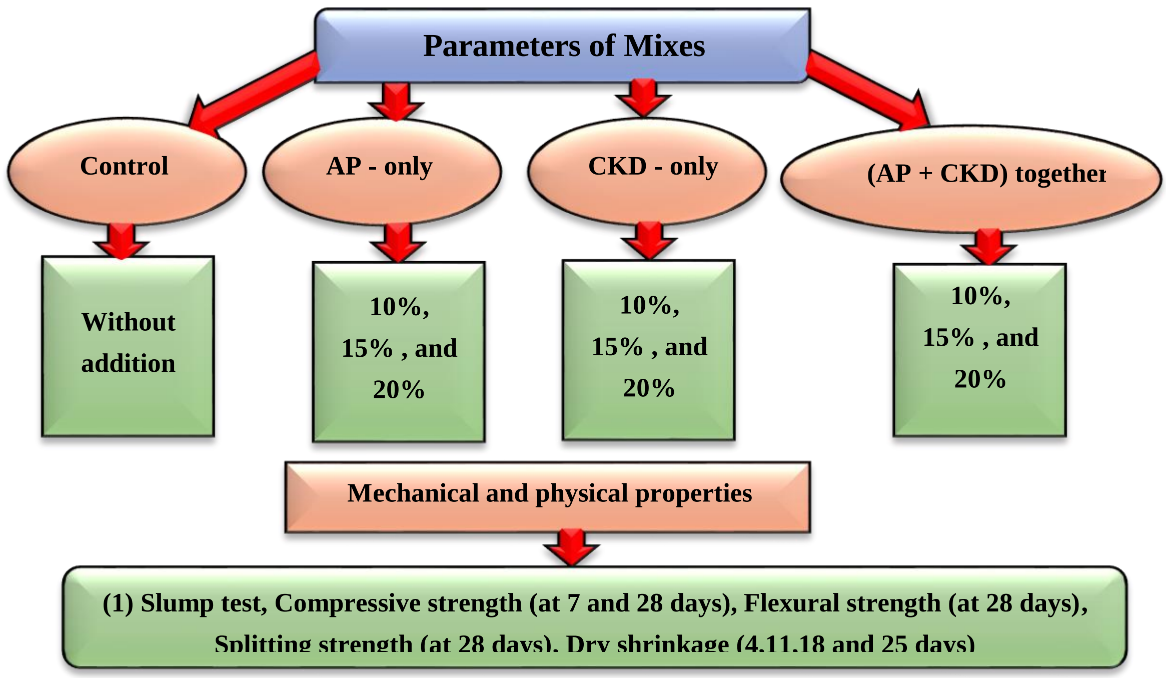

Fig. 1. Experimental plan for the study

The cement utilized within this research was CEM I 42.5 N conforming to BS EN 197-1 (EN 2000) standards. The cement, which is the focus of this study, is Egyptian Portland cement. The application method was supplied by one of the nearest ready-mix concrete plants. Since concrete is a cement-based material, it became necessary to consider the usability of the Portland cement so that expired or damp cement would be avoided. The gravel was hard, natural, and passed through a 4.76 mm aperture No. 4 mesh sieve. This study's collected sand aggregates fineness modulus ranges from 3.2 to 3.1, which must not deviate over the acceptable limits that are adhered to in the brous of Civil Engineering BS EN 196-1 BSI 2005 specifications. Cumulative gradation screening analysis of fine sand provided a value that satisfied the requirements of legislative provisions. The amount of water was appropriate within the BS EN 1008 (EN 2002), British standard. To enhance the characteristics of the concrete, the proportions of the additives, namely AP and CKD, were 10 %, 15 %, and 20 % of AP and CKD, respectively. See **Figs 1 and 2**.

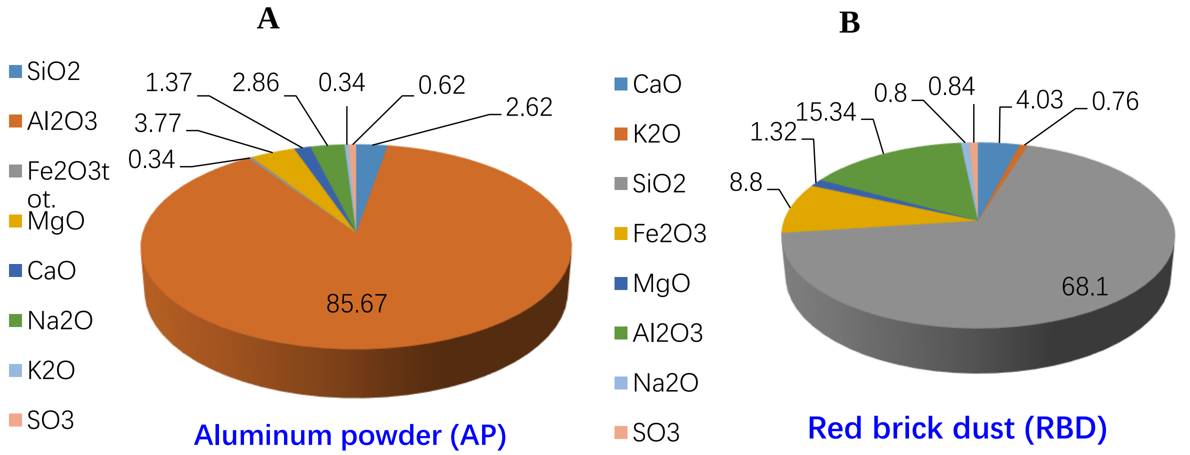

Fig. 2. A&B, Chemical compositions of aluminium powder (AP), and cement kiln dust (CKD), [7, 29, 30]

3.1.1 The steps of Synthesis AP

The AP was procured from Qena Cement Factory, Egypt. It has been illustrated in **Fig. 3**. A series of processes was also carried out to produce AP. As depicted in **Fig. 3**, the factory supplied all materials needed in bulk quantities as raw material. Then the bulk blocks were disintegrated into smaller, manageable sizes. Then, such small blocks were processed further, assisting the handling of such material since the resultant product expected from that grinding will be uniform and smooth like cement, which is a substitute for that product. However, care was taken to make the resulting substance as soft as cement.

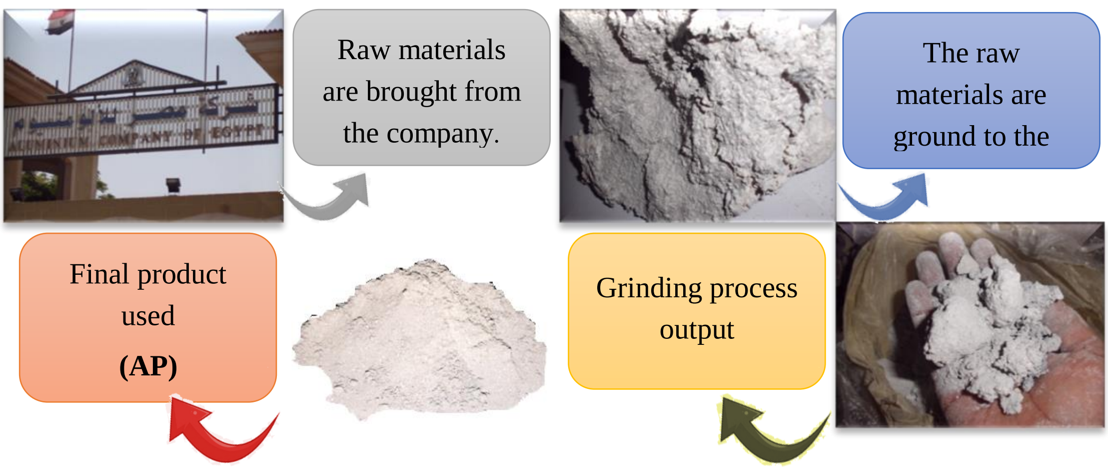

Fig. 3. The steps of Synthesis AP

3.1.2 The steps of Synthesis CKD

Raw Cement Kiln Dust (CKD) was procured as it is available from a cement manufacturing industry in Helwan, Egypt. CKD has undergone several transformations to achieve being as smooth as cement, and it is used as a partial substitute for cement in this study. See **Fig. 4.**

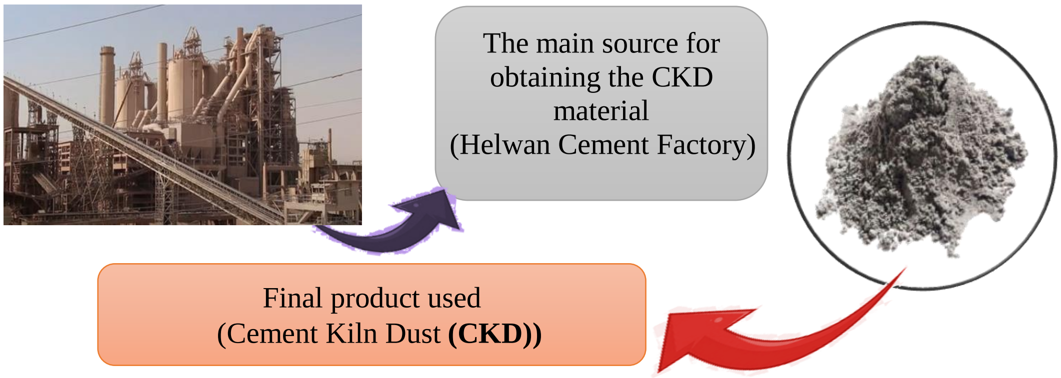

Fig. 4. The steps of CKD production

3.2 Mix proportions

Ten varieties of concrete mixes were made, each bearing the different cement replacement ratios of CKD or AP, which are 10%, 15%, and 20% cement; the proportion of sand: gravel was 2.04. However, the percentage of added water was 0.42% of the cement (**Table 1**). Therefore, the control mix was designed in such a way as to achieve equal and well-shaped concrete mix slumps. Working compositions were divided into three groups. Three group I mixes created for their CKD partial replacement ratios are 10%, 15%, and 20 % of cement. Then, three group II mixes were designed to assess the Effect of replacing cement with 10%, 15%, and 20% AP in the second group of mixes. Roughly proportionality is confirmed by the data in **Table 1**; the last group III was also called and divided into three parts: 10% CKD + AP, 15% CKD + AP, and 20% CKD + AP cement, respectively.

Table 1: Quantities of concrete mixtures (kg/m^3)

No		**Sample**	**Cement**	**Natural Sand**	**Gravel**	**Water (0.4 of cement)**	**SP**	**Cementation binder (%)**			
								CKD	AP	*(CKD and AP)	
										CKD	AP
1		C -0.0%	450.0	711.6	1067.8	180	9.0	0	0	0	0
2	Group I	CKD -10%	405.0	711.6	1067.8	180	9.0	45	0	0	0
3	Group I	CKD -15%	382.5	711.6	1067.8	180	9.0	67.5	0	0	0
4	Group I	CKD -20%	360.0	711.6	1067.8	180	9.0	90	0	0	0
5	Group II	AP - 10%	405.0	711.6	1067.8	180	9.0	0	45	0	0
6	Group II	AP - 15%	382.5	711.6	1067.8	180	9.0	0	67.5	0	0
7	Group II	AP - 20%	360.0	711.6	1067.8	180	9.0	0	90	0	0
8	Group III	*CKD + AP - 10%	405.0	711.6	1067.8	180	9.0	0	0	22.5	22.5
9	Group III	*CKD + AP - 15%	382.5	711.6	1067.8	180	9.0	0	0	33.75	33.75
10	Group III	*CKD + AP - 20%	360.0	711.6	1067.8	180	9.0	0	0	45	45

*Total substitution of (CKD and AP) = 10, 15, 20%, respectively of cement for Group III

3.3 Testing procedure

The concrete was molded into categories to ascertain and assess their mechanical properties using the control, group I with a replacement ratio of CKD, group II with a replacement ratio of AP, and group III with a replacement ratio of CKD with AP. For the design and curing conditions of the specimens, the standard applicable was the ASTM C192-02. The slump of the new concrete mixtures was established by determining the slump test of concrete using a slump test table as per the ASTM standard C1437-15. A total of sixty preparations of concrete specimens measuring 100 × 100 × 100 mm were prepared according to BS EN 196-1 up to seven days and twenty-eight meters to carry out compressive testing, and 30 concrete specimens were tested for flexural strength at a curing age of twenty-eight days, The flexural strength test is performed according to Egyptian Standard Specifications ESS 1658/2006, Tensile strength test was done as per the provision of BS 1881 Testing concrete, Part 117, and The Drying Shrinkage is performed conforming to the ASTM standard specification guidelines (C490-1986), (C 305-1982), (C 157-1986) & (C 511-1986) for material for testing concrete. Using simplified slabs, the used forms of the specimens are standard beams 25x25x280 mm, whereas one test specimens were produced for ages 4, 11, 18, and 25 days.

3.4 Design of concrete mixes

Ten types of concrete mixtures were developed. **Table 1** specifies the ratios of each of the mixes. The first was the control mix; CKD AP was not included in the preparation. The mixes were categorized as CKD, AP, and CKD plus AP for the remaining nine mixtures. Each group had 10%, 15%, and 20% CKD, AP, and CKD + AP by weight, concerning cement, keeping the cement: water ratio constant. Attempts with different mixing techniques led to the most favorable overall method for the preparation of the samples. Plant operations were carried out next, where cement flour was thoroughly mixed with other components, dry, followed by water addition. The concrete, therefore, resulted from using a particular manner of mixing those aggregates to achieve uniformity. In detail, three different tests were performed: compression for 60 cubes, bending for 30 cylinders, and dry shrinkage for 160 samples. See **Table 2**. Hence, the concrete mixtures were prepared mechanically using the following steps.

- During this step, cement, natural sand, and CKD or AP were mixed using a pan mixer for 1 minute.
- After that, a pan was used to carry out the mixing process, where water was added gradually into the pan, followed by stirring the mixture for an additional 4 minutes.
- In the next step, coarse aggregates were added for 5 minutes, and the mixing was gradually carried out to reach a uniform consistency.

Table 2. Number of samples for all mixtures

No.		**Sample**	**Compressive strength**		**Flexural strength At 28 days**	**Splitting Strength At 28 days**	**Dry shrinkage (4,11,18 and 25) days**			
			7 day	28 days			4 days	11 days	18 days	25 days
1		C -0.0%	3	3	3	3	4	4	4	4
2	Group I	CKD -10%	3	3	3	3	4	4	4	4
3	Group I	CKD -15%	3	3	3	3	4	4	4	4
4	Group I	CKD -20%	3	3	3	3	4	4	4	4
5	Group II	AP - 10%	3	3	3	3	4	4	4	4
6	Group II	AP - 15%	3	3	3	3	4	4	4	4
7	Group II	AP - 20%	3	3	3	3	4	4	4	4
8	Group III	CKD + AP - 10%	3	3	3	3	4	4	4	4
9	Group III	CKD + AP - 15%	3	3	3	3	4	4	4	4
10	Group III	CKD + AP - 20%	3	3	3	3	4	4	4	4
No. of samples per age			30	30	30	30	40	40	40	40
The Total number of test samples			60		30	30	160			
Total samples for all tests			280							

4. Results and discussions

The results that were obtained regarding the parameters of the slump test, compressive strength at 7 and 28 days, Flexural Strength at 28 days, splitting strength at 28 days, and dry shrinkage test at ages 7, 14, 21, and 28 days are presented in **Table 3**.

4.1 Fresh properties (Slump test)

Depicted in **Fig. 5** is the slump of all mixtures together with the slump value relationship of all mixtures. All mix slumps did not fall below 146 mm to 125 mm for those that contained only CKD, AP, and CKD with AP [29, 30]. Notably, as the replacement percentages increased, the Slump value went down. The recorded slump values were 146mm, 141mm, 134mm, and 131mm for mixes C -0.0%, CKD -10%, CKD -15%, and CKD -20% respectively. The slump values of the second set were

133, 129, and 125 mm for mixes AP - 10%, AP- 15%, and AP-20% 20% respectively [30, 31]. The slump values of the third set were 134, 132, and 129mm for mixes CKD+AP-10%, CKD+AP-15%, and CKD+AP-20% respectively [30, 32]. The same phenomenon was observed in all combinations, whereby an increase in the proportion of replacement caused a reduction in the Slump values and hence a reduced effect on all mixtures, as illustrated in **Fig. 6**.

Table 3. Test results for all mixtures

No.	Group	Sample	Slump test	Compressive strength 7 day	Compressive strength 28 days	Flexural strength At 28 days	Splitting Strength At 28 days	Dry shrinkage (4, 11, 18, and 25) days: 4 days	11 days	18 days	25 days
1		C -0.0%	146.0	32.12	43.24	5.55	4.81	283.74	582.41	868.68	1162.12
2	Group I	CKD -10%	141.0	41.47	53.15	7.25	6.41	298.51	616.12	924.63	1240.41
3	Group I	CKD -15%	134.0	40.52	52.65	7.11	6.22	296.63	608.52	906.41	1211.36
4	Group I	CKD -20%	131.0	38.96	50.75	6.81	5.95	295.12	605.62	905.64	1203.41
5	Group II	AP - 10%	133.0	35.75	45.62	6.01	5.23	292.32	595.32	889.12	1178.21
6	Group II	AP - 15%	129.0	33.65	43.74	5.67	4.96	290.21	588.23	870.12	1166.12
7	Group II	AP - 20%	125.0	30.32	39.62	5.02	4.33	278.45	570.13	848.62	1136.63
8	Group III	CKD + AP - 10%	134.0	37.45	48.23	6.43	5.61	293.31	604.62	892.12	1199.41
9	Group III	CKD + AP - 15%	132.0	36.87	46.71	6.17	5.38	293.12	601.78	889.58	1188.65
10	Group III	CKD + AP - 20%	129.0	32.14	42.52	5.42	4.68	283.13	579.65	860.32	1150.13

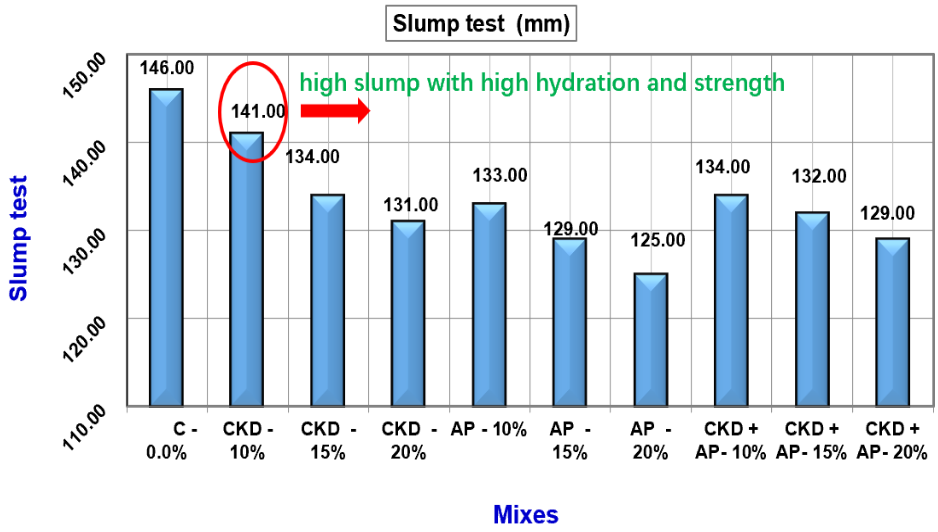

Fig.5. The Slump test of the mixtures

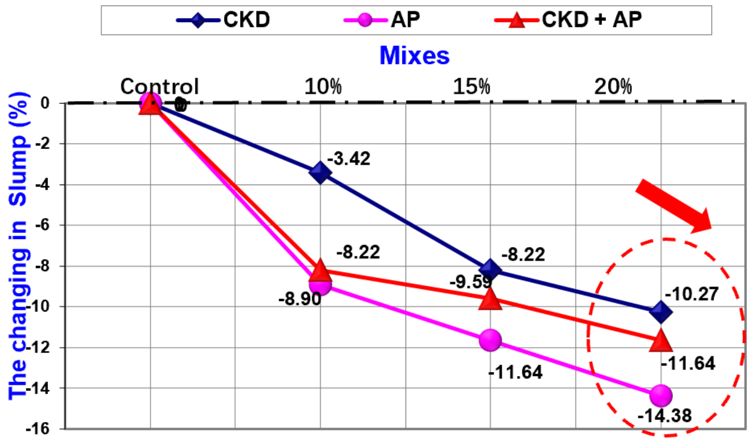

Fig. 6. Reduction in slump (%)

4.2 Mechanical properties

4.2.1 Behavior of compressive strength

Incorporating powder materials reinforced concrete's mechanical and durability parameters, encompassing compressive strength, flexural strength, and splitting strength to some extent. **Fig. 7** illustrates clearly that, along with the control concrete mix specimen, compressive strength has also increased with the addition of CKD and AP to the other concrete mix specimens [6, 33, 34]. Even at a low % replacement rate of 10%, there was an increase in all the ages' compressive strength when compared with the reference concrete mix specimens. Still, when the replacement percentage increased to 15% or 20%, there was a low increase compared to the replacement rate of 10% [35, 36]. The percentage increase in strength was different, especially in replacement rates. See **Figs 7 and 8**. Concrete that has been cured for 28 days becomes stronger. When CKD content was diminished by 10%, its peak strength of 53.15 MPa was attained. The development caused by replacement was fastest when the control mixture with the addition was absent (0.0%), it recorded a strength of 43.24 MPa, the lowest [37, 38]. Comparatively, there were significant increases in strengths when the compressive strengths at 7 days and 28 days were contrasted [39, 40]. The replacement materials were nearly insignificant, hence the ease of the cement paste and gel to envelop all the concrete mix ingredients. There was a corresponding increase in compressive strength with replacement materials incorporated in the mixtures. There was adequate strength in the stiff matrices containing replacement materials [41, 42].

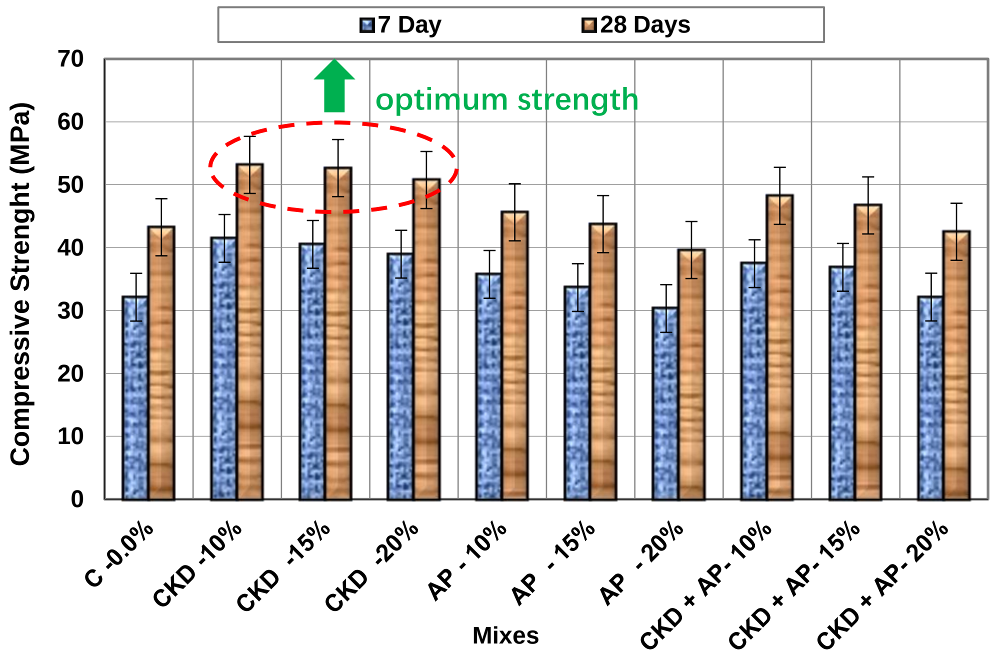

Fig. 7. Compressive strength at 7 days and 28 days

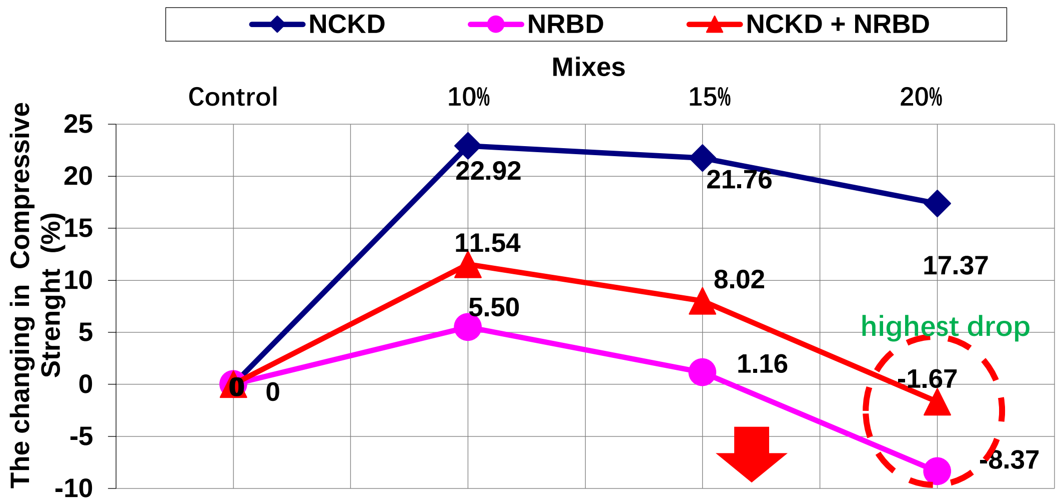

Fig. 8. The change in Compressive Strength (%)

4.2.2 Behavior of flexural strength

Replacement materials are positively affected by Interaction and attract water. These studies showed that the high chemical activity of powder materials makes it easier to form additional nucleation sites and leads to more C-S-H phase formation, which influences concrete cubes' strength [43, 44]. If CKD and AP include a mix of oxides like SiO_2, Al_2O_3, etc., then small cement particles with pozzolanic activity might enhance the hydration, and less bulky ettringites and calcium hydrates may be formed. Because of the small diameter of small particles, matrix packing density can be improved due to small particle additions. Powder materials offer better enhancement of the flexural strength and flexural/compressive (%) when used in Partial replacement of the cement [45, 46]. Replacement materials in cement composites offer enhanced mechanical properties. See **Figs 9 and 10**.

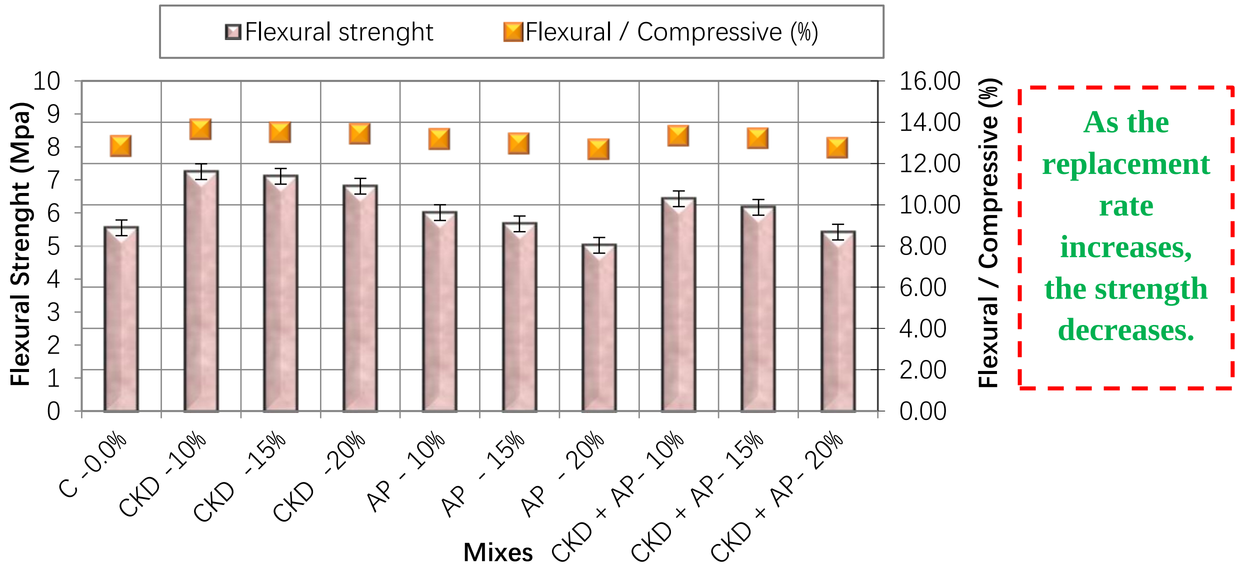

Fig. 9. Flexural strength of the mixtures and flexural strength/compressive strength (%)

The maximum strength attained by peak was when this ratio reduced CKD content to about 10% which was 7.25 MPa [47, 48]. The strength increase was most significant at 10% replacement, when compared with the control mixture, 5.55 MPa recorded a low value. It is observable, though, that there were indeed considerable increases in strengths when comparing the splitting strengths concerning the test results [49, 50].

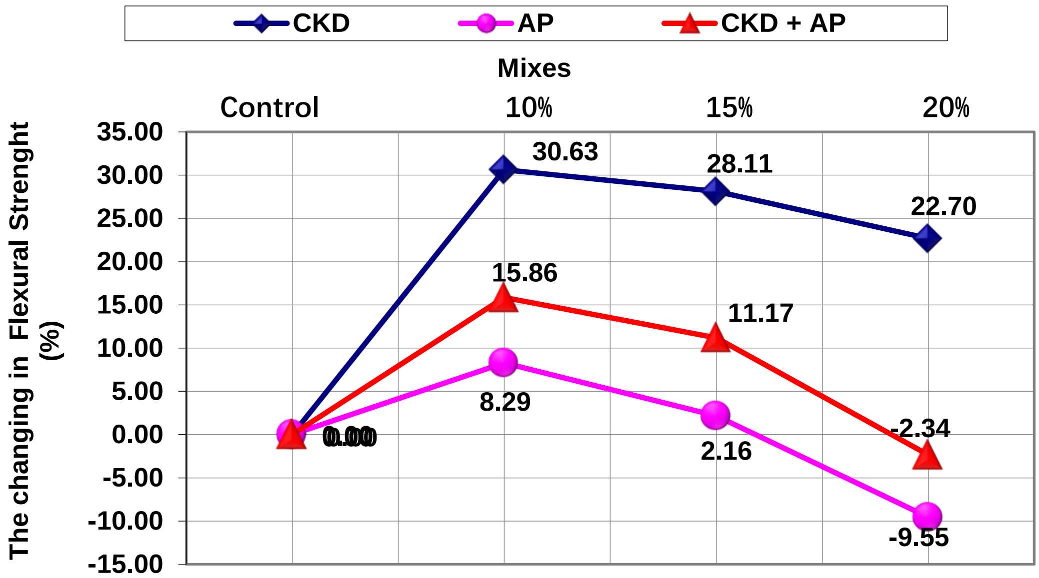

Fig. 10. The change in Flexural Strength (%)

4.2.2.1 The flexural and compressive strength relationship

This section examines the interdependence of the compressive and flexural strength of the concrete. **Fig. 11** shows this dependence, and the quality-suit line for the connection is as Eq**. (1)**.

$$y = 0.1653x - 1.5608$$
(1)

x is the compressive strength (MPa), y is the flexural strength (MPa), and R^2 = 0.9984. **Fig.11** displays the compressive versus flexural strength relationships. This connection was deduced for all the concrete mixes studied, as there were significant differences in the results owing to the numerous mixes [51, 52]. From **Fig. 11**, it was evident that line matches had a strong relation and that the differences were no longer as vast as the results obtained. Hence, it could be said that the degree of R^2, which indicates the flexural strength's ability to predict the specimens' compressive strength, is relatively high. It was noted that in high concrete compressive strength, the concrete bending strength also increased [53, 54].

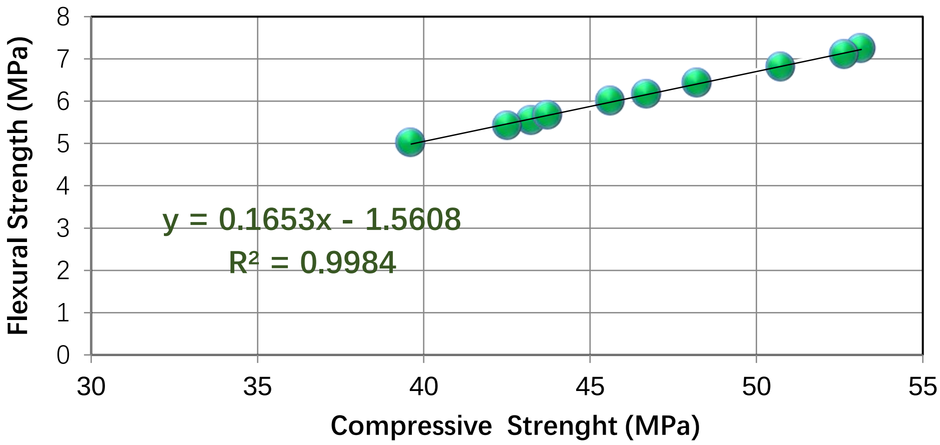

Fig. 11. Relationship between flexural and compressive strength

4.2.3 Behavior of Splitting Strength

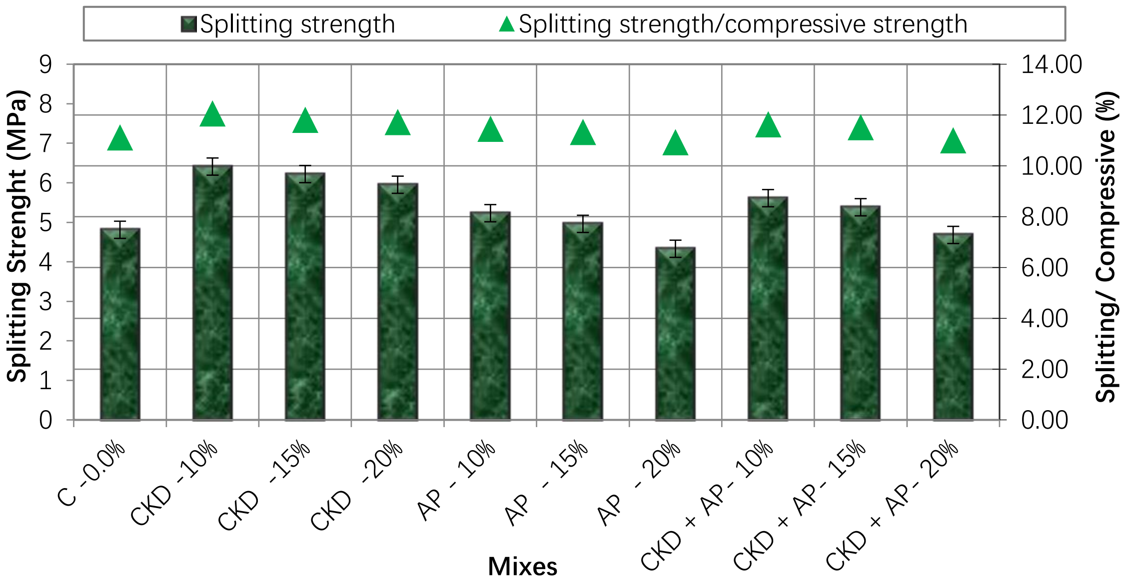

Fig. 12. Splitting strength of the mixtures and Splitting strength/compressive strength (%)

As is straightforwardly depicted in **Fig. 12**, the splitting strength of the control concrete mix specimen recorded a ratio of 4.81 MPa; there has also been an upward movement concerning the amount of CKD and AP being replaced in the other concrete mix specimens. The Splitting strength of group I were 6.41 MPa,6.22 MPa, and 5.95MPa for mixes CKD -10%, CKD -15%, and CKD -20%, respectively [55, 56], for group II, The recorded Splitting strengths were 5.23 MPa,4.96 MPa, and 4.33MPa for mixes AP -10%, AP -15% and AP -20% respectively, and finally group III were recorded 5.61 MPa,5.38 MPa, and 4.68MPa for mixes CKD + AP- 10%, CKD + AP- 15% and CKD + AP- 10%respectively. However, when CKD content was replaced with 10% the peak value of 6.75 MPa was achieved. On the other hand, the highest replacement rate was observed, which showed the lowest strength of 4.33 MPa with a mixture of AP-20%. Nevertheless, it can be said that growth was virtually level: even with the least percentage of variation in the Splitting strength of concrete at 28 days [57, 58].

Powder materials are more effective when used in partial cement replacement rather than completely replacing it in terms of splitting strength and splitting / compressive (%) enhancement. In most instances, the crystallization of replacement materials into the existing cement composites upgraded the mechanical properties [59-61]. Refer to **Figs 12 and 13**.

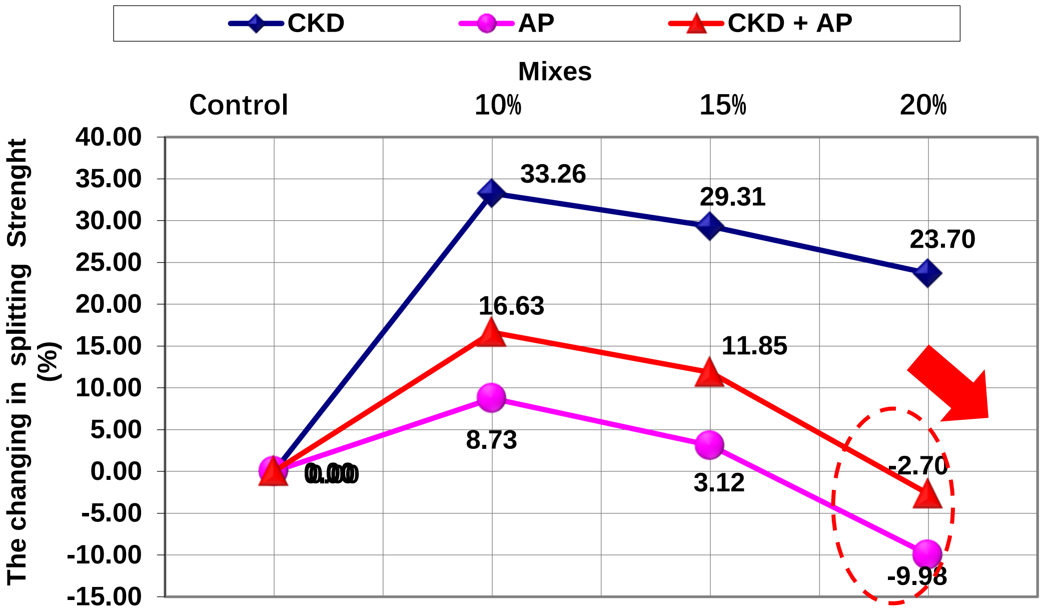

Fig. 13. The change in splitting Strength (%)

4.2.3.1 The splitting and compressive strength relationship

In this portion of the study, the correlation concerning concrete compressive strength and splitting strength is assessed as shown in **Eq. (2).**

$$Y = 0.1513x - 1.6969 \quad (2)$$

y is the splitting strength (MPa), x is the compressive strength (MPa), and R^2 = 0.9964.

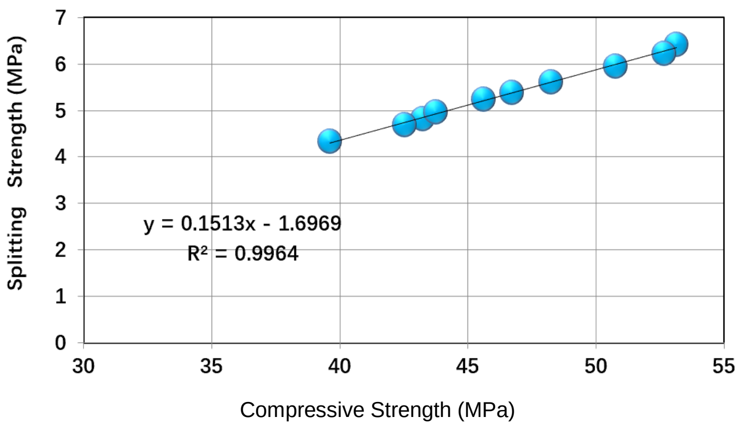

Fig. 14. Relationship between Splitting and compressive strength

Fig. 14 gives some information related to the diagrams on the inter-relations between the specimens' compressive and splitting strengths. This linkage was even more typical for all variants of concrete because the mix variations taken are the cause of the dominant variation in the results [62, 63]. In **Fig.14,** it was also apparent that, as regards line match, there was a rather good match in terms of direction towards that connection. The value of R^2, which answers the question of how well the compressive strength of those specimens performs as a function of the splitting strength, also means that R2 was appropriate. In the future, regarding the increase in strength in splitting, it was also evident that there is a high dependence upon increasing the compressive strength of the concrete [64, 65].

4.2.4 Behavior of dry shrinkage in the short-term

As illustrated in **Fig. 15**, six samples were removed from the molds after 4, 11, 18, and 25 days of curing, which revealed that as curing days increased, drying shrinkage reduction from 4-day-old to that of 25-day-old samples constitutes the best performance within the **Figs** because of hydration inhibition. The matrix possesses some self-desiccation properties, and more water may be transported to the external surface by the pore-filling Effect, and some evaporation happens [66, 67]. All samples had almost similar values of dry shrinkage, which was observed in all samples, as indicated in **Figs. 15, and 16**; however, there was a reduction in samples containing AP, which was higher than in CKD. The inclusion of drying shrinkage information gained in the dependent materials showed that when compared to the control (295.12×10^{-6} mm/mm at 4 days), replacement of 10, 15 and 20% CKD made the drying shrinkage strains to be 278.45 × 10−6, 283.13×10^{-6} and 283.74×10^{-6} mm/mm respectively [68, 69]. The samples with 10%, 15% and 20% AP in dried samples showed increased drying shrinkage relaxation strains of 293.12×10^{-6} mm/mm, 293.31×10^{-6} mm/mm and 298.51×10^{-6} mm/mm at 4 days when compared with the control samples at 295.12×10^{-6} mm/mm. It was also noted from the subsequent work that while admixing CKD-10% and AP-10% at all ages resulted in the highest decrease in shrinkage. Samples containing CKD- 10% and AP-10% demonstrated a lower dehydration shrinkage strain than the other samples, with the Highest replacement rate of CKD and AP samples, implying that the CKD-10% and AP- 10% samples had the best shrinkage properties [70, 71]. Changes in drying shrinkage were noticed while adding CKD to AP samples, which a higher internal relative density could explain due to more secondary C-S-H formation and pores filled with replacement materials. They reduced the shrinkage of the concrete, which means that as the replacement rate rose and the volume of fine constituents increased within the concrete, so did the extent of the concrete drying shrinkage [72-74].

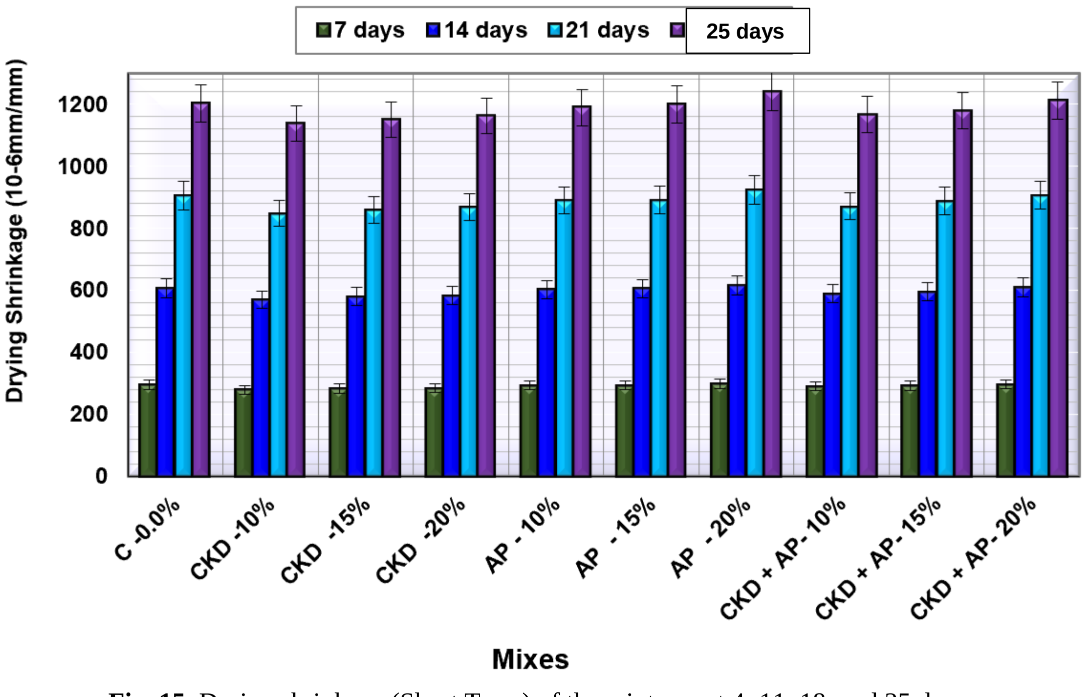

Fig. 15. Drying shrinkage (Short Term) of the mixtures at 4, 11, 18, and 25 days.

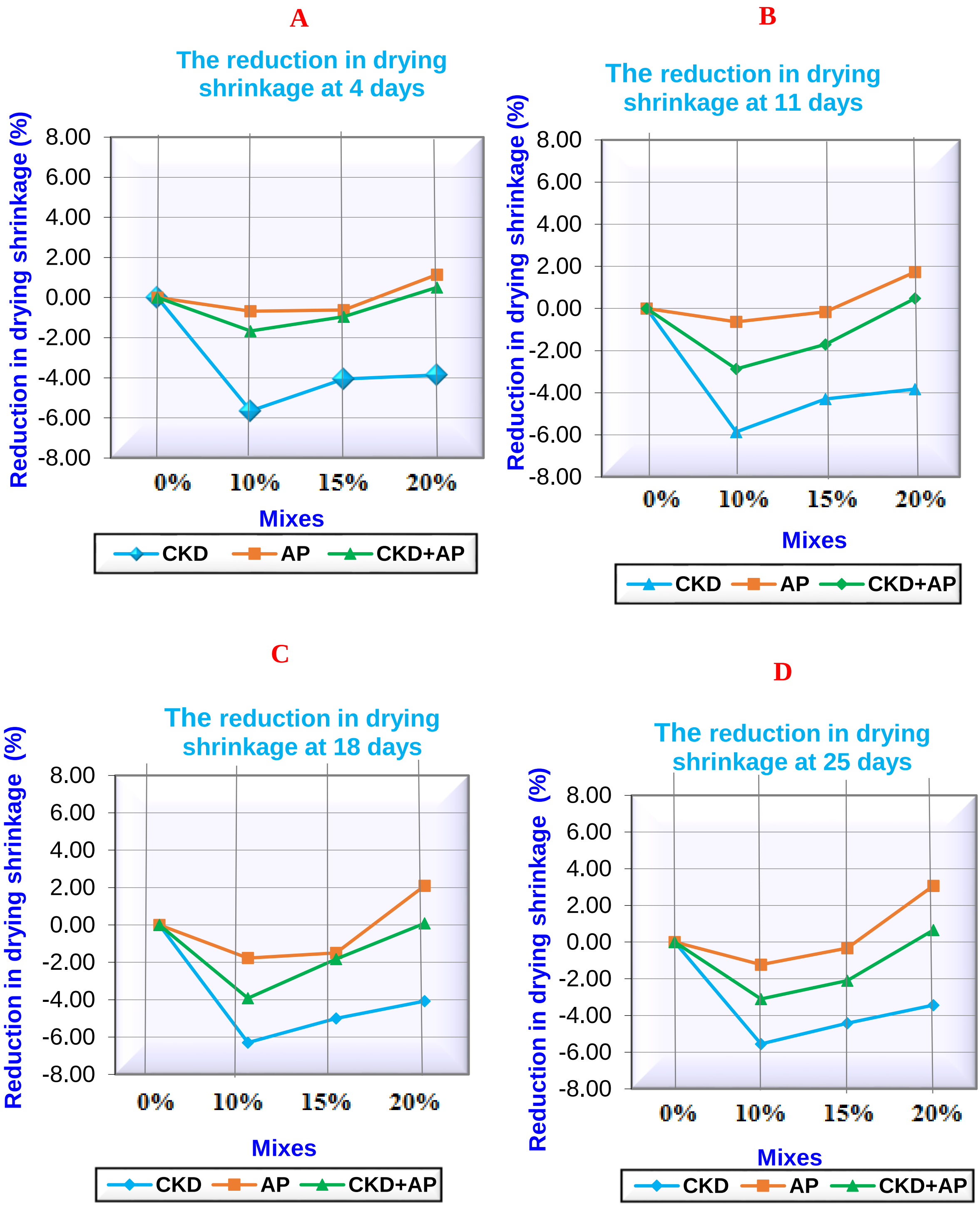

Fig. 16. A, B, C &, D, Reduction in dry shrinkage (%)

5 Conclusion

The essence of this research was to evaluate the properties of green concrete when other types of Waste CKD and AP, as a new approach towards the promotion of green concrete, were used in replacement. In terms of the identified mechanical features, the study provided the following results:

Notably, as the replacement percentages were increased, the slump value went down, and all mix slumps did not fall below 146 mm to 125 mm for those that contained only CKD, AP, and CKD with AP.

When CKD content was diminished by 10%, its peak strength of 53.15 MPa was attained, and there was a corresponding increase in compressive strength with replacement materials incorporated in the mixtures.

Powder materials offer better enhancement of the flexural strength and flexural/compressive (%) when used in Partial cement replacement, especially at the 10% cement replacement rate.

When CKD content was replaced with 10% the peak value of 6.41 MPa was achieved. On the other hand, the highest replacement rate was observed, which showed the lowest strength of 4.33 MPa with a mixture of AP-20%. Nevertheless, it can be said that growth was virtually level: even the smallest percentage of variation in the Splitting strength of concrete at 28 days.

Samples containing CKD- 10% and AP-10% demonstrated a lower dehydration shrinkage strain than the other samples, with the Highest replacement rate of CKD and AP samples, implying that the CKD-10% and AP- 10% samples had the best shrinkage properties at 10% replacement.

Recommendation

Studying the durability of concrete containing Cement Kiln Dust (CKD) and Aluminium powder (AP) at a ratio of 10%.

Studying the structural Behavior of reinforced concrete elements containing CKD and AP at temperatures up to 300 ℃ for heat durations up to 1 and 2 hours.

Studying the long-term tests and analyzing the optimum mixtures' microstructure.

Studying the mixtures at high ratio replacement possibilities used in non-load-bearing concrete types, to save on the amount of cement used in concrete.

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CRediT authorship contribution statement

All authors contributed equally to 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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