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The Usage Of Di-Aluminated Meta-Kaolin As A Mineral Admixture In Concrete

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Abstract - **An industrial by-product of the manufacturing of aluminum sulphate is Dealuminated Metakaolin (DK). It harms the environment since it contains aluminum sulphate contamination. Aluminum Sulfate Company in Egypt's (ASCE) production is thought to be 200 tons per day, or about 70,000 tons annually [1]. The majority of this garbage is disposed of in a sanitary landfill, putting agricultural soil, the soil surface, people's health from inhaling dust, and the ecosystem's and cultivators' health at risk. In terms of how this garbage will affect Egypt's future. As a result, recycling techniques don't use to produce sustainable products, this presents a significant problem. Due to its high alkalinity and high volume of production, which is estimated to be around 7.5 million tons annually [1].**

INTRODUCTION

Dealuminated Metakaolin

Dealuminated Metakaolin (DK) is highly corrosive, a serious environmental hazard, a storage problem due to the harm it causes to soil and other life forms, and presents a significant problem for disposal. Despite the fact that there are recycling processes for alum reuse, particularly given the fact that it contains raw materials for the production of iron, silicon, and aluminum. It is still dumped as waste because doing so is less expensive than continuing to mine for new ores. Only 1% to 2% of garbage is recycled; the remainder is disposed away, either wet or dry, in a sanitary landfill [1]. Not only has it led to the invasion of farmland, groundwater pollution, and the potential for dam failure, but it has also caused in the loss of waste resources because some advantageous components in DK are not sufficiently reused. DK is one of the most problematic issues facing the aluminum sulphate industry, and prominent aluminum firms and organizations are investigating alternative solutions. The study suggests employing the DK material as a mineral admixture in the concrete industry as an additive to the cement content as a means of solving the issue. The suitability of pozzolanic minerals used as a mineral additive in the production of concrete depends on their pozzolanic activity. The pozzolanic activity is dependent on the quantity of active ingredients, such as SiO_2 and Al_2O_3, present in the reaction with calcium hydroxide produced as a result of calcium silicate production [1]. The activity of pozzolanic compounds depends on the amount of active silica present. In pozzolanic cement paste, this active silica dissolves and precipitates as calcium silicate hydrate, or CSH. The pozzolanic reaction is applied here [1].

A. Review of Literature

This part represents the previous studies for the researchers and engineers familiar with and referred to A lot of cases applied for different percentage of adding or replacing of DK to the cement to compare between the compressive strengths. Interestingly, the majority of these investigations have taken care of a situation of adding the material to the cement content and act as an additive in case and as a partial replacement for the cement in other case.

Stefano Cangiano and Antonio Princigallo [3], examined DK as an additive to concrete and as a potential clinker alternative in cement. DK was examined as a replacement for micro silica in concrete, in part because of its great fineness and pozzolanic activity. Additionally, a comparison with the behavior observed after concurrent usage of metakaolin was made. DK, a possible major component of cement, demonstrated the ability to achieve compressive strength values in standard mortar tests (EN 196-1) that were extremely comparable to cement with the same amount of SF. Finally, based on the findings of the analysis, DK appeared to be a material worth considering in terms of performance/cost ratio [3]. Utilizing DK as a potential principal component of cement, they came to the conclusion that while Portland cement's rheology is a little off, the compressive strength values for mortar tests are almost identical to those obtained for samples containing cement and silica fume.

Hassan K. S. Hassan et. al. [5], in a thorough investigation, Khaled SaadElDin used metakaolin and DK to examine the formation and characteristics of alkali activated slag. In the research, high alkaline activator of NaOH with three different concentrations, three different alkaline activator contents, three different ratios of added water, eight different ratios of DK from 0% to 60% as an additive or as a partial replacement of the Slag content, and five different ratios of MK from 40% to 80% as a partial replacement of the Slag content were used [5]. Additionally, AAS is a significant improvement over other novel binders since it uses a medium that is alkaline. The proof of significant plastic shrinkage for such a binder is the main obstacle.

Saadeldin Khaled et. al. [6], conducted a thorough investigation using waste aluminum sulphate to examine the Metakaolin Geopolymer-based binder. The study used 12 different ratios of DK from 0% to 60% of the MK content, high alkaline activator of NaOH with three different

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concentrations, alkaline activator levels, and water addition ratios [6]. The initial setting time and the flowability index of the DK modified MK Geopolymer were the two new features that were the subject of the investigation. Wet curing and ambient curing, two distinct curing regimes, were used. Additionally, the UCS was examined at various ages both in the summer and in the winter.

Abdullah, Nabil, et. al., [4] conducted an experiment to determine whether siliceous wastes from DK and metakaolin (MK). Testing was done on DK's chemical make-up and physical characteristics at weight ratios ranging from 0 to 60%. Using standard cubes, compressive strength was tested after 7 and 28 days [4]. Researchers studied how DK affected specific gravity, porosity, and mechanical properties. Utilizing cutting-edge equipment like thermogravimetric/thermogravimetric derivative (TGA), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR), the interior microstructure and hydration were studied [4]. The results demonstrate the viability of using DK as a pozzolanic material. DK mixture is a good pozzolanic material. Despite the fact that MK Geopolymer is a promising binder with early strength gains and no curing requirements, there are still many obstacles in the way of its widespread acceptance as a binder in the mainstream industry because of the lack of industry knowledge about its full potentials and benefits to be gained when using such a new binder.

B. The Main Objective

The main objective of the research paper is to study experimentally create high-performance impermeable concrete using four different DK contents, namely 0, 5, 10, and 15% of cement content, either as an additive or as a replacement for cement content, using two different grades of cement, namely 42.5 N and 52.5 N, with two different cement contents, namely 350 kg/m^3, and 400 kg/m^3. A total of 28 concrete mixtures were cast. For DK-modified concrete, the ultimate compressive strength at three different ages; 28, 56, and 91 days, measured on three specimens at each age. Finally, conclusions on the research works are presented and recommendations for work are presented.

II. EXPERIMENTAL PROGRAM

A. Concrete Design

The experimental program includes fabrication of concrete mixtures using two different types of OPC namely: OPC – Grade 42.5 N and OPC – Grade 52.5 N. Two different cement contents that are commonly used in the trail namely: 350 kg/m^3 and 400 kg/m^3 are applied. Two different methods of using DK in concrete were investigated namely addition and replacement method. In the addition method, DK is added to the cement content by three ratios namely: 5, 10 and 15%. In the replacement method, DK is used as partial replacement of the cement by three ratios namely: 5, 10 and 15%. In additional to, the control mixture which is free of DK material. A total of seven mixtures were casted in each group of certain cement type and cement content. A total of 28 concrete mixtures were divided into four groups namely: 350 kg/m^3 – 42.5 N, 400 kg/m^3 – 42.5 N, 350 kg/m^3 – 52.5 N and 400 kg/m^3 – 52.5 N. Coarse aggregate used was crushed dolomite of two separate sizes and equal portions namely: S1 (9.5 mm) and S2 (19 mm). Fine aggregate used was natural sand of size less than 4.75 mm and greater than 0.075 mm. A constant water cement ratio (WC) was used at 45% of the total Cementous Content of each mixture. The weight of the cement content is constant for the addition DK mixtures, while the weight of the DK content increased as DK% increased from 0, 5, 10 and 15%.

B. Experimental Tests

The mixture was checked was clean and without any dusts or rubbish from the previous mixtures to be sure that there is no any outsource that could make negative effect on the mixture, as the dust may absorb some of water and make a dry effect on the mixture. The weights of sand as a fine aggregate, coarse aggregate with two different sizes of stone, cement, DK, water and additive. Ultimate compressive strength for hardened concrete were measured at 28, 56 and 91 days using standard concrete mold 100 x 100 x 100 mm according to ASTM C109-99 [2]. UCS was measured on three specimens at each age.

"Fig. 1, Specimens of cubes"

C. Experimental Results

As can be seen in TABLE I and Fig. 2, the comparison between UCS of DK modified concrete using cement grade 42.5 N for cement content 350 and 400 kg/m^3 for replacement DK percentages of 0, 5, 10 and 15 % of the cement content. Also, as can be seen in Fig. 2, which make comparison between UCS for replacement and addition of DK to the concrete.

TABLE I. COMPRESSIVE STRENGTH FOR REPLACEMENT & ADDITION DATA OF DK (350 kg/m^3 - 42.5 N)

Code of Mixture	***Replacement Failure Load***			***Addition Failure Load***		
	Age of Test (Day)	***(MPa)***	***SD***	***Age of Test (Day)***	***(MPa)***	***SD***
0.350.42^5	28	36	3.06	28	36	3.00
	56	40		56	39	
	91	42		91	42	
5.350.42^5	28	36	4.00	28	37	4.00
	56	40		56	41	
	91	44		91	45	
10.350.42^5	28	37	4.51	28	39	4.00
	56	41		56	43	
	91	46		91	47	
15.350.42^5	28	39	4.51	28	40	4.51
	56	43		56	45	
	91	48		91	49	

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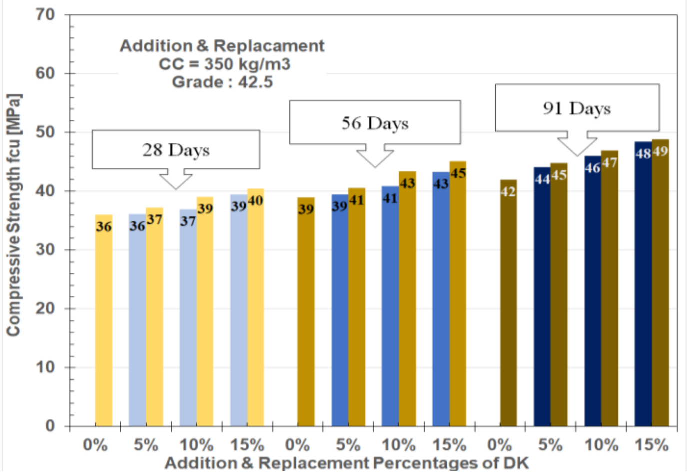
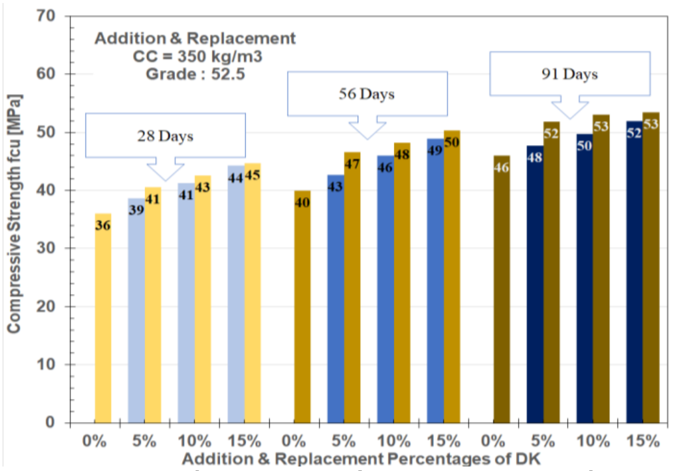


“Fig. 2, Comparison between concrete ultimate compressive strength using replacement and additional DK for cement content (350 kg/m^3 – 42.5 N)”

As can be seen in TABLE I and Fig. 2, the UCS of DK modified concrete is affected by: age, cement content, cement grade and percentage of addition DK. For 0.350.42^{5}, UCS increased to 36, 39 and 42 MPa at 28, 56 and 91 days respectively. Also, for 5.350.42^{5}, UCS increased to 37, 41 and 45 MPa at 28, 56 and 91 days respectively. For 10.350.42^{5}, UCS increased to 39, 43 and 47 MPa at 28, 56 and 91 days respectively. Also, for 15.350.42^{5}, UCS increased to 40, 45 and 49 MPa at 28, 56 and 91 days respectively. The results showed that there is a significant increase in UCS as the percentage of replacement and addition of DK increased from 0, 5, 10 and 15 % of the cement content for the same cement grade, and cement content at all ages. As can be seen at replacement state of DK, for 5.350.42^{5}, UCS increased to 100, 100 and 105 % at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.350.42^{5}, UCS increased to 103, 105 and 110 % at 28, 56 and 91 days respectively. For 15.350.42^{5}, UCS increased to 108, 110 and 114 % at 28, 56 and 91 days respectively. As can be seen at addition state of DK, for 5.350.42^{5}, UCS increased to 103, 105 and 107% at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.350.42^{5}, UCS increased to 108, 110 and 112 % at 28, 56 and 91 days respectively. For 15.350.42^{5}, UCS increased to 111, 115 and 117 % at 28, 56 and 91 days respectively.

TABLE II. COMPRESSIVE STRENGTH FOR REPLACEMENT & ADDITION DATA OF DK (350 kg/m^3 - 52.5 N)

Code of Mixture	*Replacement Failure Load*			*Addition Failure Load*		
	Age of Test (Day)	*(MPa)*	*SD*	*Age of Test (Day)*	*(MPa)*	*SD*
0.350.42^{5}	28	36	5.03	28	36	5.03
	56	40		56	40	
	91	46		91	46	
5.350.42^{5}	28	39	4.51	28	41	5.51
	56	43		56	47	
	91	48		91	52	
10.350.42^{5}	28	41	4.51	28	43	5.00
	56	46		56	48	
	91	50		91	53	
15.350.42^{5}	28	44	4.04	28	45	4.04
	56	49		56	50	
	91	52		91	53	

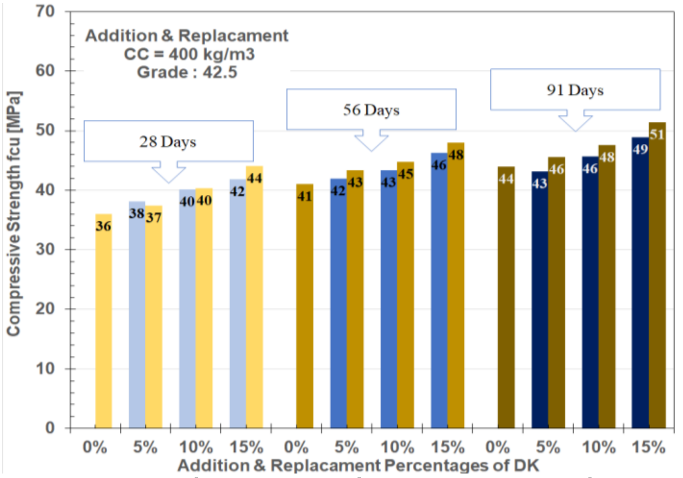


“Fig. 3, Comparison between concrete ultimate compressive strength using replacement and additional DK for cement content (350 kg/m^3 – 52.5 N)”

As can be seen in TABLE II and Fig. 3, the UCS of DK modified concrete is affected by: age, cement content, cement grade and percentage of addition DK. For 0.350.52^{5}, UCS increased to 36, 40 and 46 MPa at 28, 56 and 91 days respectively. Also, for 5.350.52^{5}, UCS increased to 41, 47 and 52 MPa at 28, 56 and 91 days respectively. For 10.350.52^{5}, UCS increased to 43, 48 and 53 MPa at 28, 56 and 91 days respectively. Also, for 15.350.52^{5}, UCS increased to 45, 50 and 53 MPa at 28, 56 and 91 days respectively. The results showed that there is a significant increase in UCS as the percentage of replacement and addition of DK increased from 0, 5, 10 and 15 % of the cement content for the same cement grade, and cement content at all ages. As can be seen at replacement state of DK, for 5.350.52^{5}, UCS increased to 108, 108 and 104 % at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.350.52^{5}, UCS increased to 114, 115 and 109 % at 28, 56 and 91 days respectively. For 15.350.52^{5}, UCS increased to 122, 123 and 113 % at 28, 56 and 91 days respectively. As can be seen at addition state of DK, for 5.350.52^{5}, UCS increased to 106, 105 and 105% at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.350.52^{5}, UCS increased to 114, 110 and 110 % at 28, 56 and 91 days respectively. For 15.350.52^{5}, UCS increased to 125, 117 and 116 % at 28, 56 and 91 days respectively.

TABLE III. COMPRESSIVE STRENGTH FOR REPLACEMENT & ADDITION DATA OF DK (400 kg/m^3 - 42.5 N)

Code of Mixture	*Replacement Failure Load*			*Addition Failure Load*		
	Age of Test (Day)	*(MPa)*	*SD*	*Age of Test (Day)*	*(MPa)*	*SD*
0.350.42^{5}	28	35	4.58	28	35	4.58
	56	41		56	41	
	91	44		91	44	
5.350.42^{5}	28	38	2.65	28	37	4.58
	56	42		56	43	
	91	43		91	46	
10.350.42^{5}	28	40	3.00	28	40	4.04
	56	43		56	45	
	91	46		91	48	
15.350.42^{5}	28	42	3.51	28	44	3.51
	56	46		56	48	
	91	49		91	51	

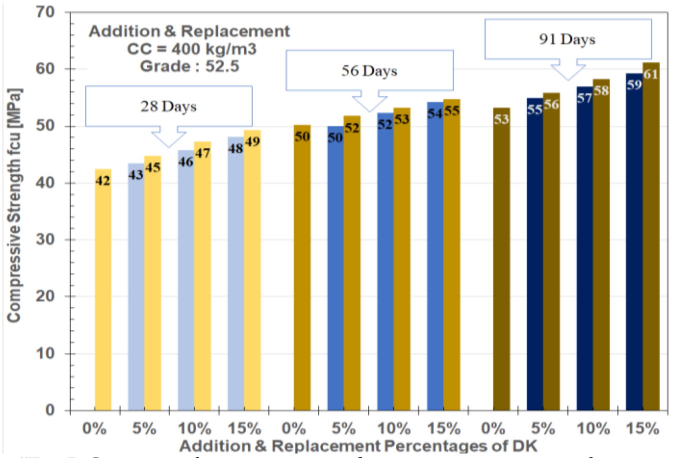


"Fig. 4, Comparison between concrete ultimate compressive strength using replacement and additional DK for cement content (400 kg/m^3 – 42.5 N)"

As can be seen in TABLE III and Fig. 4, the UCS of DK modified concrete is affected by: age, cement content, cement grade and percentage of addition DK. For 0.400.42^5, UCS increased to 35, 41 and 44 MPa at 28, 56 and 91 days respectively. Also, for 5.400.42^5, UCS increased to 37, 43 and 46 MPa at 28, 56 and 91 days respectively. As can be seen at replacement state of DK, for 5.400.42^5, UCS increased to 109, 102 and 100 % at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.400.42^5, UCS increased to 114, 103 and 105 % at 28, 56 and 91 days respectively. For 15.400.42^5, UCS increased to 120, 112 and 111 % at 28, 56 and 91 days respectively. As can be seen at addition state of DK, for 10.400.42^5, UCS increased to 40, 45 and 48 MPa at 28, 56 and 91 days respectively. Also, for 15.400.42^5, UCS increased to 44, 48 and 51 MPa at 28, 56 and 91 days respectively. The results showed that there is a significant increase in UCS as the percentage of replacement and addition of DK increased from 0, 5, 10 and 15 % of the cement content for the same cement grade, and cement content at all ages. For 5.400.42^5, UCS increased to 114, 118 and 113% at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.400.42^5, UCS increased to 119, 120 and 115 % at 28, 56 and 91 days respectively. For 15.400.42^5, UCS increased to 125, 125 and 115 % at 28, 56 and 91 days respectively.

TABLE IV. COMPRESSIVE STRENGTH FOR REPLACEMENT & ADDITION DATA OF DK [400 - 52.5]

Code of Mixture	*Replacement Failure Load*			*Addition Failure Load*		
	Age of Test (Day)	*(MPa)*	*SD*	*Age of Test (Day)*	*(MPa)*	*SD*
0.350.42^5	28	43	5.13	28	43	5.13
	56	50		56	50	
	91	53		91	53	
5.350.42^5	28	44	5.51	28	45	5.57
	56	50		56	52	
	91	55		91	56	
10.350.42^5	28	46	5.51	28	47	5.51
	56	52		56	53	
	91	57		91	58	
15.350.42^5	28	48	5.51	28	49	6.00
	56	54		56	55	
	91	59		91	61	



"Fig. 5, Comparison between concrete ultimate compressive strength using replacement and additional DK for cement content (400 kg/m^3 – 52.5 N)"

As can be seen in TABLE IV and Fig. 5, the UCS of DK modified concrete is affected by: age, cement content, cement grade and percentage of addition DK. For 0.400.52^5, UCS increased to 42, 50 and 53 MPa at 28, 56 and 91 days respectively. Also, for 5.400.52^5, UCS increased to 45, 52 and 56 MPa at 28, 56 and 91 days respectively. For 10.400.52^5, UCS increased to 47, 53 and 58 MPa at 28, 56 and 91 days respectively. Also, for 15.400.52^5, UCS increased to 49, 55 and 61 MPa at 28, 56 and 91 days respectively. The results showed that there is a significant increase in UCS as the percentage of addition of DK increased from 0, 5, 10 and 15 % of the cement content for the same cement grade, and cement content at all ages. As can be seen at replacement state of DK, for 5.400.52^5, UCS increased to 109, 100 and 104 % at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.400.52^5, UCS increased to 110, 104 and 108 % at 28, 56 and 91 days respectively. For 15.400.52^5, UCS increased to 114, 108 and 111 % at 28, 56 and 91 days respectively. As can be seen at addition state of DK, for 5.400.52^5, UCS increased to 107, 104 and 106% at 28, 56 and 91 days respectively corresponding to the control specimen. For 10.400.52^5, UCS increased to 120, 106 and 109 % at 28, 56 and 91 days respectively. For 15.400.52^5, UCS increased to 117, 110 and 115 % at 28, 56 and 91 days respectively.

III. CONCLUSION

Ultimate compressive strength for hardened concrete were measured, using standard concrete mold 100 x 100 x 100 mm according to ASTM C109-99 [2]. The UCS of DK modified concrete, showed that there is a significant increase in UCS as the percentage of addition of DK increased from 0, 5, 10 and 15 % of the cement content for the same cement grade, and cement content at all ages. This behaviour may be due to the effect of pozzolanic reaction between micro silica in DK and Calcium hydroxide phase in cement. The percentages of increase of UCS are affected by increasing the percentage of addition of DK gradually, and as the age of specimens increased from 28, 56 and 91 days for all cement contents and cement grades. The percentages of increase of UCS of DK modified concrete is almost constant and negligibly affected by the cement content of specimens or the cement grade. The maximum percentage of increase of UCS of DK modified concrete takes place at the age of 91 day by 61 MPa at addition state of DK by 15 % at cement content 400 kg/m^3 with grade 52.5 N that represents 115 % of the control specimen at the same age.

The comparison represented between UCS of DK modified concrete using cement grade 42.5 N for cement content 350 and 400 kg/m^3 for replacement DK percentages of 0, 5, 10 and 15 % of the cement content. Also, the comparison between UCS for addition and replacement of DK to the concrete. Data showed acceleration from the results from Cement Content CC = 350 kg/m^3 at Ordinary Portland Cement OPC = 42.5 N to the maximum at cement content = 400 kg/m^3 at OPC = 52.5 N. The first part in the Fig for CC = 350 kg/m^3 at OPC = 42.5 N the results between the addition data and replacement data are variable, as the replacement data less in range 94 to 99 % than addition data in the chart. Also, in the charts of CC = 400 kg/m^3 at OPC = 42.5 N, at CC = 350 kg/m^3 at OPC = 52.5 N and at CC = 400 kg/m^3 at OPC = 52.5 N. These charts showed that there is increasing in the UCS from the replacement case to the additional one, however, it is not the different one or gab found between the results when it compared to the cement content used in the mixtures of specimens and the replacement content of cement by DK up to 15 %.

Generally, the difference between addition and replacement results is not too large. In addition to, as can be see that the replacement for the cement content up to 15% industrial by product material and less expensive as a result saving the cost when it compared by the addition data and the cement content used there. The discussion of the results showed that it is similar to the previous papers and trails that represented in the literature review, however the weakest point in this trial is there is no peak point in the results. The significant increase in UCS as the cement content of specimens increased from 350 to 400 kg/m3 for the same cement grade, and percentages of addition of DK at all ages. This behavior was the same either for control specimens or DK modified specimens. There is a significant increase in UCS as the cement grade of specimens increased from 42.5 N to 52.5 N for the same cement content, and percentages of addition of DK at all ages. This may be due to the increase of the percentage of the cement clinker in grade 52.5 N over grade 42.5 N. Unfortunately, the experimental program fell short to pin point the optimum percentage of addition and replacement of DK in concrete.

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