Effect of adding Silica fume to the Cement Kiln Dust (CKD)

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Abstract: This paper reports the results of a study conducted to assess the effect of adding silica fume to the cement kiln dust on the compressive strength of concrete mixes.Fifty nine concrete mixes were prepared to determine the effect of adding cement kiln dust (CKD) to concrete mixes as a replacement quantity by weight from cement. The substitution percentage were (0% control, 10%, 20%, 30%, 40%, 50%, 60% and 100 %). Also percentage of silica Fume of (3%, 6%, 9%) has been added to all mixes. The results of substitution sand in lieu of cement and CKD had been obtained also and compared with those determined in case of CKD substitution.
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1. Introduction

Cement manufacturing is a critically important industry in the United States and throughout the world. In2006, U.S. cement plants produced 99.8 million metric tons of cement. Worldwide production accounted for about 2.5 billion metric tons. As with most large manufacturing industries, by-product materials are generated. These industrial by-product and waste materials must be managed responsibly to insure a clean and safe environment. Cement kiln dust (CKD) is a significant by-product material of the cement manufacturing process. Over the past several years dramatic advances have been achieved in the management and use of cement kiln dust, thus reducing its dependency on landfill disposal.[5]

In a survey that included 60% of the cement manufacturing plants in the USA, it was found that due to its high alkaline content, large quantities of CKD could not be returned to the kiln [2],but the higher alkalinity and finer particles in addition to their (sometimes) cementitious properties, make these materials usable for several applications such as waste solidification[10],replacement of Portland cement in concrete block manufacturing and ready mix concrete [11] and use as agricultural soil amendments[14].the presence of free lime (CaO), the high alkali content and the high fineness of CKDs also make them potentially valuable materials for stabilizing soils [6]. R. Siddique[12] concluded that Cement Kiln Dustand wood ash could be successfully used as a partial replacement of cement in making controlled low –strength materials (CLSM).

El – Sayed *et al.*[7] have investigated the effect of CKD on the compressive strength of cement paste and on the corrosion behavior of embedded reinforcement The Study reported that up to 5% substitution of CKD by weight of cement had no adverse effect either on cement paste strength nor the reinforcement passivity.

A similar conclusion was reached in an investigation carried by Batis *et al.*[4] Where it was found that when CKD and blast furnace slag are in proper ratio in ordinary Portland cement, the compressive strength and corrosion resistance of the mix increase.

Salem *et al.*[13] have studied the hydration of cement pastes containing granulated slag and CKD made with and without silica fume. It was reported in their study that the hydraulic reactivities of granulated slag and silica fume as activated by raw CKD are relatively high as compared with those activated by washed CKD.

In cementitious compounds, silica fume works on two levels, the first one described here is a chemical reaction called the "pozzolanic" reaction[1]. The hydration (mixing with water) of Portland cement produces many compounds, including calcium silicate hydrates (CSH) and calcium hydroxide (CH). The CSH gel is known to be the source of strength in concrete. When silica fume is added to fresh concrete it chemically reacts with the CH to produce additional CSH. The benefit of this reaction is twofold; increased compressive strength and chemical resistance. The bond between the concrete paste and the coarse aggregate, in the crucial interfacial zone, is greatly increased, resulting in compressive strengths that can exceed 15,000 psi. The additional CSH produced by silica fume is more resistant to attack from aggressive chemicals than the weaker CH. The second function that silica fume performs in cementitious compounds is a physical one. Because silica fume is 100 to 150 times smaller than a cement particle it can fill the voids created by free water in the matrix. This function, called particle packing, refines the microstructure of concrete, creating a much denser pore structure. Impermeability is dramatically increased, because silica fume reduces the number and size of capillaries that would normally enable contaminants to infiltrate the concrete. Thus silica fume modified concrete is not only stronger, it lasts longer, because it's more resistant to aggressive environments. As a filler and pozzolan, silica fume's dual actions in cementitious compounds are evident throughout the entire. The aim of this study is to determinate the effect of adding the cement kiln dust by substitution it by weight of cement with different ratios and the effect of adding silica fume to the mix to activate the chemical reaction of calcium hydroxide to introduce CHS

2. Research significance

No researches have been published on the use of different ratios of silica fume to improve the strength of concrete made with different ratios of CKD. With the increasing of environmental concerns about reducing, reusing and recycling materials. It was very useful to mix two by – product and investigate the potential benefits of using silica fume with CKD in concrete mixes

3. Materials and methods

3-1 Cement

Ordinary Portland Cement From Qena Factory of cement had been used in this study and the chemical composites are shown in table(1).The compressive strength test for cement had been done and the results was

(182 -274) kg/cm^2 for 3 days and 7 days respectively.3-2 Cement Kiln Dust (CKD) is a fine, highly alkaline powder from the same factory and Table 1 shows the chemical composites of CKD used in this study.

3-3 Silica Fume

By- product resulting during the production process of silicon and ferrosilicon. Silica fume was initially viewed as a cement replacement material but recently it has been used to provide concrete with very high compressive strength or very high level of durability or both[1].Silica fume used in this study was brought from ferrosilicon factory, table 2 shows the chemical composites of silica fume. The surface area was determinate and equal to 20000 m2/kg, Blaine.

3-4 Coarse aggregate

Crushed stone (Dolomite with MNS 37.5 mm), and volumetric weight 1600 kg/ m3 was used.

3-5 Fine aggregate

Siliceous sand has been used in the concrete as a fine aggregate, sieve analysis had been done and the fineness modulus Obtained was 2.8.

3-6 Super plasticizer

Sikamaint 163 has been added as accelerator with dosage 2.5% by cement weight.

Table (1) Chemical Composites for Cement and CKD

Component	Portland cement (%)	Cement Kiln Dust (%)
SiO2	20.6	15.8
AL2O3	4.5	3.6
Fe2O3	3.6	2.8
CaO	62.5	63.8
MgO	2.6	1.9
SO3	2.7	1.7
K2O	0.5	3.0
Na2O	0.2	0.3
CL-	0.01	1.1

Table (2) Chemical Composites of Silica Fume

Component	Mean percentage (%)
SiO_2	93.65
AL_2O_3	.28
Fe_2O_3	.58
CaO	.27
MgO	.25
SO_3	.02
K_2O	.49

3-7 Mix Design

Standard practice for selecting proportions of normal concrete (ACI 211.1) [1] has been used to provide the all concrete mixes. The mix ingredients shown in table (3).

3-7-1 Mix Design Criteria

- Compressive strength 300 kg/ cm2
- Slump (75 – 100) mm
- MNS for Coarse Agg. 37.5 mm
- FM for sand 2.8

Table (3) Concrete Mix Ingredients

Water (kg/m3)	Cement (Kg/m3)	Coarse Agg.(kg/m3)	Fine Agg.(kg/m3)
181	335	1136	758

3-8 Experimental Program

3-8-1 Mix proportioning

Fifty nine concrete mixes were obtained to determine the effect of adding cement dust to concrete mixes as a replacement quantity by weight from cement. The substitution percentage were (0%

control, 10%, 20%, 30%, 40%, 50%, 60% and 100 %), as mentioned in table (4).

Silica fume was added to all the previous mixes with different percentage 3%, 6%, 9%). For pure cement tree mixes B,C and D with the same ingredients with silica fume percentage (3%,6% and 9%) were prepared to have the average results showing the effect of silica fume on pure cement mixes. Mixes of group (G) six mixes prepared with different substitution percentage of CKD (10%, 20%, 30%, 40%, 50%, 60%) for G1,G2,G3,G4,G5 and G6 respectively and as mentioned in table (5). Mixes of group (H) six mixes prepared with different substitution percentage of Sand (10%, 20%, 30%, 40%, 50%, 60%) for H1,H2,H3,H4,H5 and H6 respectively Mixes of group I,J, and K were the same ingredients of Group (G) but with additional percentage of silica fume (3%,6% and 9%) respectively. Mixes of groups L,M and N were the same ingredients of Group (H) but with additional percentage of silica fume (3%,6% and 9%) respectively.

Table (4) Mix Proportioning without Silica Fume

Mix No.	Cement Dust (%)	Cement dust by weight	Water (Lit./m3)	Cement (Kg/m3)	Coarse Agg.(kg/m3)	Fine Agg.(kg/m3)
Mix No. APure Cement Control	0%	0	181	335	1136	758
Mix No. G1 90%C+ 10%CKD	10%	33.5	181	301.5	1136	758
Mix No. G2 80%C+ 20%CKD	20%	67	181	268	1136	758
Mix No. G3 70%C+ 30%CKD	30%	100.5	181	234.5	1136	758
Mix No. G4 60%C+ 40%CKD	40%	134	181	201	1136	758
Mix No. G5 50%C+ 50%CKD	50%	167.5	181	167.5	1136	758
Mix No. G6 40%C+ 60%CKD	60%	201	181	134	1136	758

3-8-2 Test Method

Six cubes had been prepared for each mix, curing duration was done by submersing all samples for seven days in water tank. Three cubes out of six tested after 7 days and the rest were tested after 28 days. The compressive strength and different Variables were plotted As shown in table (5).

4-Results and Discussions

Table (5) Compressive strength for Pure Cement groups and its average

Cementatious Materials	Mix No.	A1		A2		A3		A4	
		Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days
Pure Cement Control	**A**	223	294	225	293	218	285	210	296
	(A1-A6)	A5		A6		**Average(A1-A6)**			
		Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days		
		224	296	213	283	**219**	**291**		

Table (6) Compressive strength for Pure Cement plus different silica fume percentage groups and its average

Cementatious Materials	Mix No.	Group 1		Group 2		Group 3		Average of Group 1,2and 3	
		Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days	Strength 7 Days	Strength 28 Days
C + SF 3%	B	238	309	240	310	234	300	**237**	**306**
C + SF 6%	C	248	310	248	317	240	306	**245**	**311**
C + SF 9%	D	261	336	254	330	245	320	**253**	**329**

Table (7) Compressive strength for Pure CKD with and without Sand

Cementatious Materials	Mix No.	Strength 7 Days	Strength 28 Days
CKD (pure)*	E	**45**	**67**
CKD + Sand**	F	**20**	**25**

*Pure CKD (without adding sand) **CKD + Sand (with adding sand)

- For mix No. (A) average compressive strength for six mixes from (A1 – A6) was (219 kg/cm^2, 291 kg/cm^2) after 7, 28 days respectively
  As shown in table (6)
- For mix No.(B1, B2and B3) average compressive strength (237 kg/cm^2, 306kg/cm^2) after 7, 28 days respectively
- For mix No.(C1,C2 and C3)average compressive strength (245 kg/cm^2, 311kg/cm^2) after 7, 28 days respectively
- For mix No.(D1,D2 and D3)average compressive strength (253 kg/cm^2, 329kg/cm^2) after 7, 28 days respectively
- As shown in table (7) for mix No. (E) pure CKD which means 100% substitution of CKD,0% cement without adding fine aggregate (sand). The average compressive strength for three cubes 15X15X15 was 45 kg/cm^2 after 7days and average of the rest three cubes was 67kg/cm^{2}after 28days
- For mix No. (F) pure CKD which means 100% substitution of CKD,0% cement but with adding fine aggregate (sand). The average compressive strength for three cubes was 20 kg/cm^2 after 7days and average of the rest three cubes was 25kg/cm^2 after 28days
- Mixes group from (G – N) the results were mentioned in table (8) with the different substitution ratios under Group (1 -6)

Table (8) Compressive strength Results for Cement, CKD, Sand and Silica Fume mixes

Cementatious Materials	Mix No.	10%* Group 1		20%* Group 2		30%* Group 3		40%* Group 4		50%* Group 5		60%* Group 6	
		St. 7 Days	St. 28 Days	St. 7 Days	St. 28 Days	St. 7 Days	St. 28 Days	St. 7 Days	St. 28 Days	St. 7 Days	St. 28 Days	St. 7 Days	St. 28 Days
C + CKD	G	202	276	200	260	185	245	144	219	142	187	140	184
C + Sand	H	210	287	210	270	192	256	138	184	122	156	130	174
C + CKD + SF 3%	I	212	289	210	275	190	254	180	248	172	196	154	204
C + CKD + SF 6%	J	225	301	222	280	197	263	192	255	183	205	163	216
C + CKD + SF 9%	K	235	324	230	290	205	275	198	269	194	245	168	223
C + Sand + SF 3%	L	220	296	218	280	200	264	182	240	136	156	146	194
C + Sand + SF 6%	M	231	307	235	289	212	278	198	265	154	166	164	218
C + Sand + SF 9%	N	249	331	243	298	220	290	206	279	178	196	180	240

*Substitution Percentage for CKD in Mix No. G, I, J and K
*Substitution Percentage for Sand in Mix No. H, L, Mand N

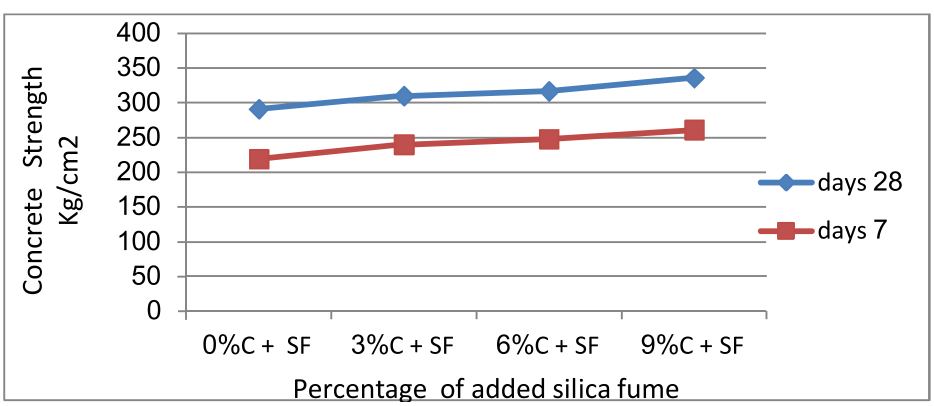
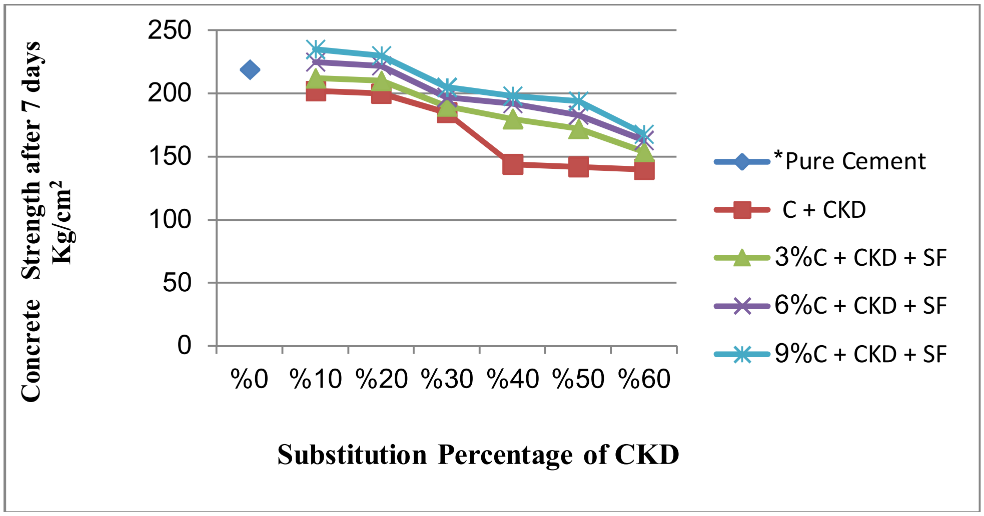
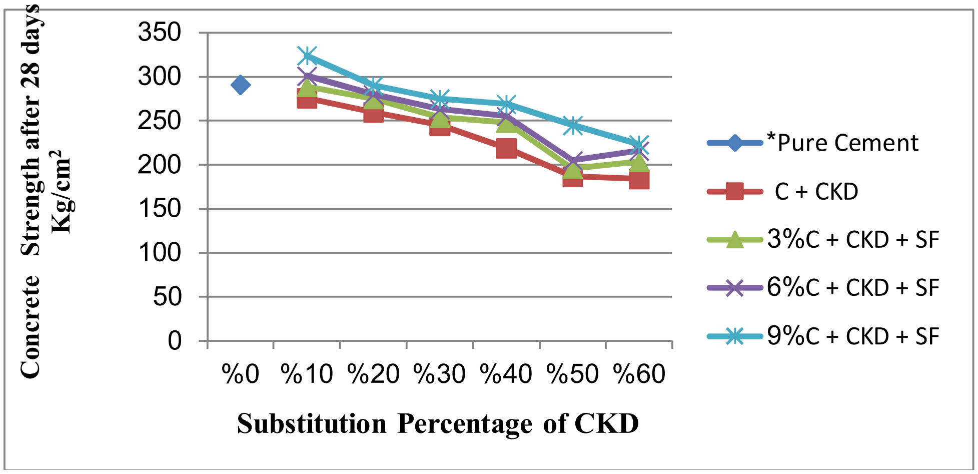


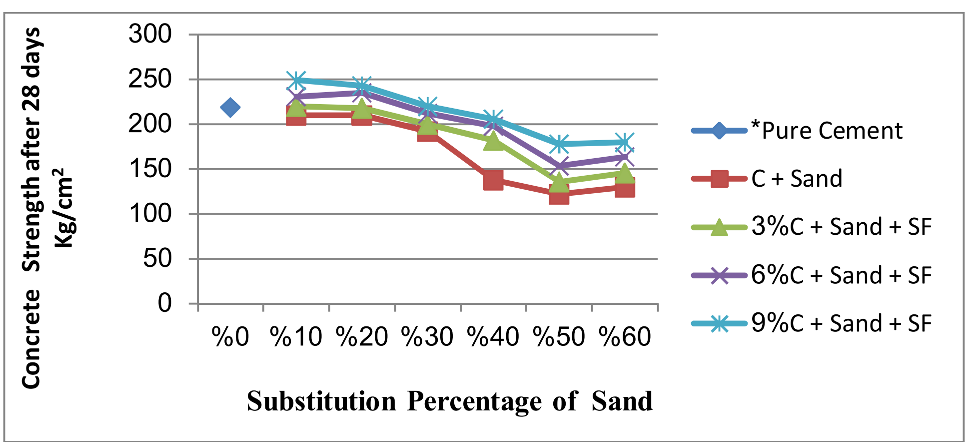
Fig (1) Concrete strength Versus Percentage of added Silica Fume



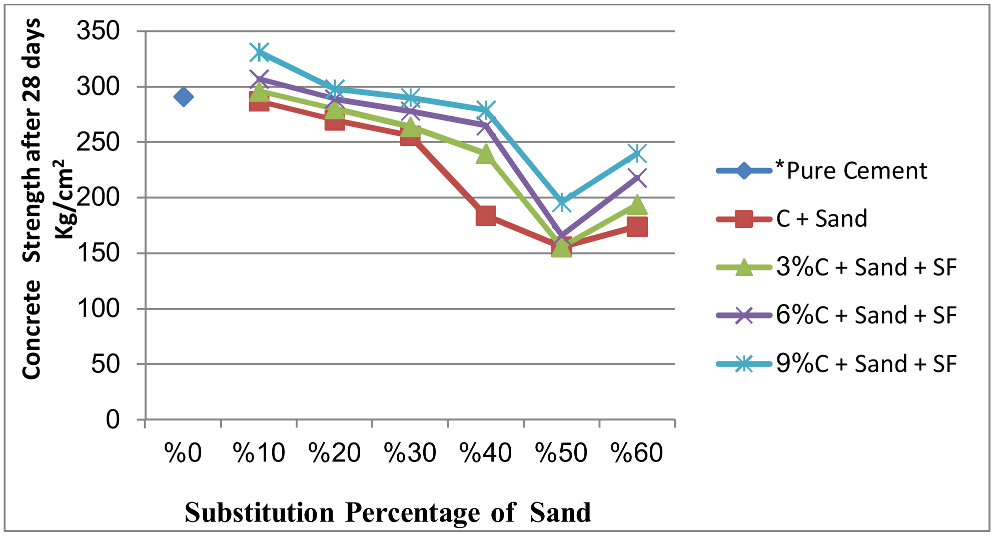
Fig(2) Concrete strength 7 days Versus Substitution percentage of CKD



Fig(3) Concrete strength 28 days Versus Substitution percentage of CKD



Fig(4) Concrete strength 7 days Versus Substitution percentage of Sand



Fig(5) Concrete strength 28 days Versus Substitution percentage of Sand

Discussion

From table (5) the reference compressive strength was obtained from mix No.A (pure cement) the average value for the six mixes were(219 kg/cm^2, 291 kg/cm^2) after 7, 28 days respectively. All the results were compared with those two values. Mixes No.B, C, and D had an average strength (237,245 and 253 kg/cm$^{2)}$) after7days respectively and had an average strength (306,311 and 329 kg/cm^2) after 28 days see table (6)

Fig (1) shows clearly the trend of the results which indicates that the increasing in strength according to adding silica fume were 8%,12% and 16 % at the early age (7days) for 3%, 6% and 9% of silica fume after 28 days the percentage of increasing strength were 5.2%, 6.9% and 13% see table (9)

Mix No.E (pure CKD without sand) the average compressive strength was 45 and 67 kg/cm^2 which causes reduction in compressive strength by 80% at early age (7days) 77% after 28 days, see table (7,9)

Mix No. F (Pure CKD with sand) the results indicated big reduction in strength91% and 91.5% which is more than mix E by about 14%.Mixes No. (G) the results as shown in figs(2,3,6) indicated a reduction in strength for substitution CKD of cement by percentage 10%, 20%, 30%, 40%, 50% and 60%For early age (7days) 7.7%, 8.7%,15.5%, 34%, 35% and 36 %.After 28 days5%,10.7%, 15.8%, 25%, 35.7%, and 36.8%. Mixes No.(I), silica fume was added by 3% from cement weight, it increases the strength compared with mixes No. (G) After 7 days by 5%,5%, 2.7%, 25%, 21%,and 10% see fig (2)After 28 days by 4.7%, 5.7%, 3.7%, 13%,4.8% and 10.8% see fig(3) Mixes No. (J), silica fume was added by 6% from cement weight, it increases the strength compared with mixes No. (G) After 7 days by 11.4%,11%, 6.5%, 33%, 28.8%, and 16.4% see fig(2) After 28 days by 9%, 7.6%, 7.3%, 16.4%, 9.6% and 17.4% see fig(3) Mixes No. (K), silica fume was added by 9% from cement weight, it increases the strength compared with mixes No. (G) After 7 days by 16.3%, 15%, 10.8%, 37.5%, 36.6%, and 20% see fig(2) After 28 days by17.4%, 11.5%, 12.2%, 22.8%, 31% and 21.2 % see fig (3).Mixes No. (H) the results as shown in figs(4.5) indicated a reduction in strength for substitution Sand of cement by percentage 10%, 20%, 30%, 40%, 50% and 60% For early age (7days) 4 %, 4.1%, 8.8%, 37%, 44% and 40 % see fig (6), also after 28 days 1.4%, 7.2%, 12.%, 36.8% 46.4% and 40.2% Mixes No.(L), silica fume was added by (3%) from cement weight, it increases the strength compared with mixes No. (H) After 7 days by 4.8%, 3.8%, 4.2%, 31.9%, 11.5%, and 12.3% see fig (4).After 28 days by 3.14%, 3.7%, 3.13%, 30.43%, 0% and 11.5% see fig(5). Mixes No. (M), silica fume was added by 6%) from cement weight, it increases the strength compared with mixes No. (H) After 7 days by 10%,11.9%, 10.4%, 43.5%, 26.2%, and 26.2% see fig(4). After 28 days by 7%,7%, 8.5%, 44%,6.4% and 25.3% see fig(5). Mixes No. (N), silica fume was added by (9%) from cement weight, it increases the strength compared with mixes No. (H) After 7 days by 18.6%, 15.7%, 14.6%, 49.3%, 45.9.6%, and 38% see fig(4). After 28 days by 15.3%, 10.4%, 13.3%, 51.63%, 25.6% and 38.5% (see fig (5)**).**

Table (9) Percentage of Strength Increasing or reduction according to the substitution percentages and adding silica fume

Mix No.	Cementatious Materials	(%) of Silica Fume	Strength Value (7-28)days Kg/cm^2	(%) strength Increasing 7 days)	(%) Strength Increasing (28 days)	(%) strength Reduction 7 days)	(%) Strength Reduction (28 days)
A	Pure Cement	0%	(219-291)	0%	0%	-	-
B	Pure Cement	3%	(237-306)	8.2%	5.2%	-	-
C	Pure Cement	6%	(245-311)	12%	7%	-	-
D	Pure Cement	9%	(253-329)	16%	13%	-	-
E	Pure CKD	0%	(45-67)	-	-	79%	77%
F	Pure CKD + Sand	0%	(20-25)	-	-	91%	91.4%
G	C+CKD (10%-60%)	0%	(202-140) - (276-184)	-	-	(8% - 52%)	(5% - 36.7%)
H	C+ Sand (10%-60%)	0%	(210-130) - (287-174)	-	-	(4% - 55%)	(1.4% - 40%)
I	C+CKD (10%-60%)	3%	(212-154) - (289-204)	-	-	(3% - 47%)	(0% - 30%)
J	C+CKD (10%-60%)	6%	(225-163) - (301-216)	2.7% *	3.4%*	25.6% **	25.8%**
K	C+CKD (10%-60%)	9%	(235-168) - (324-223)	7.3% *	11.3%*	23.3%**	23.4%**
L	C+ Sand (10%-60%)	3%	(220-146) - (296-194)	0% *	1.7%*	33.3%**	33.3%**
M	C+ Sand (10%-60%)	6%	(231-164) - (307-218)	5.5% *	5.5%*	25.1%**	25.1%**
N	C+ Sand (10%-60%)	9%	(249-180) - (331-240)	13.7% *	13.7%*	17.8%**	17.5%**

*Substitution CKD or Sand by 10%

** Substitution CKD or Sand By 60%

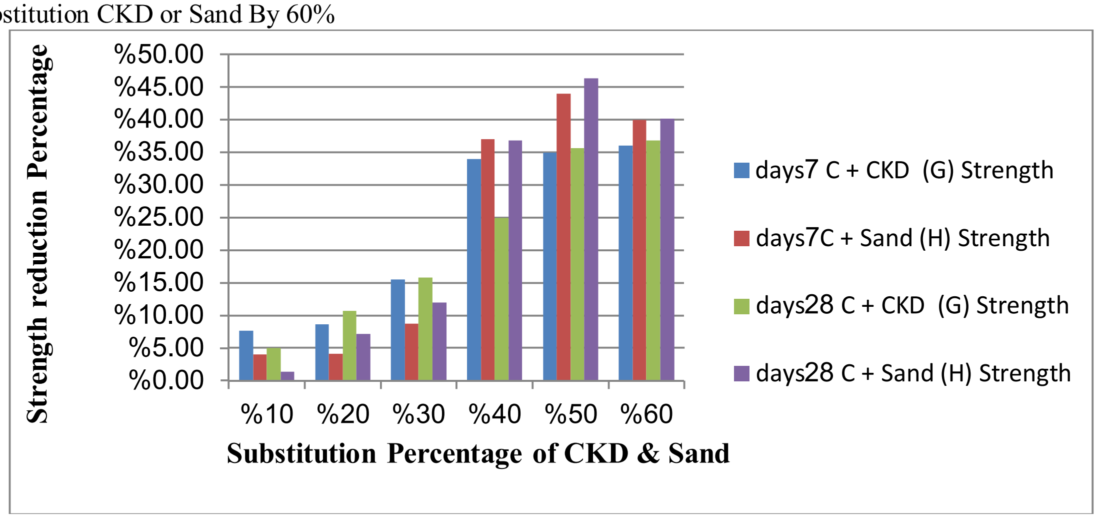


Fig (6)Percentage of Strength reduction for substitution percentage

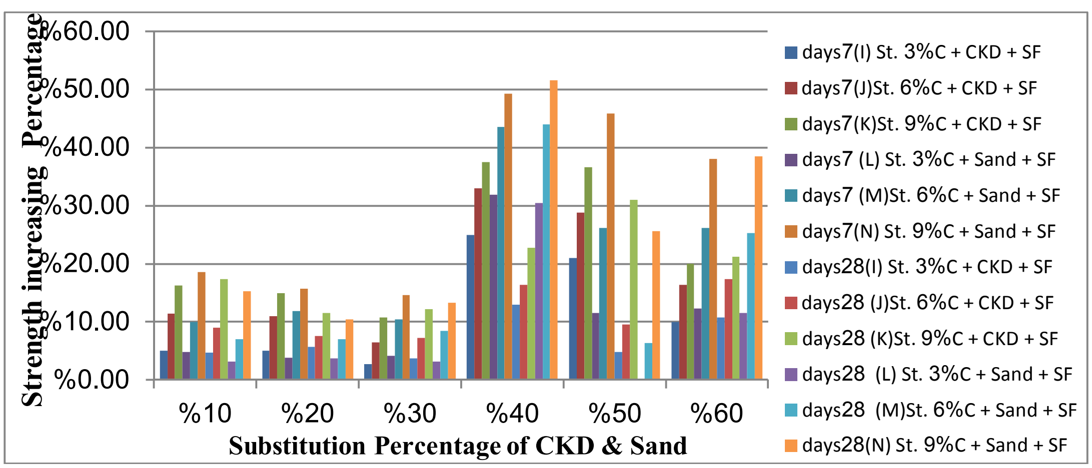


Fig (7) Percentage of Increasing Strength for substitution CKD, Sand and Silica Fume

Fig (1) shows the trend of increasing the compressive strength according to the increasing of the percentage of silica fume in concrete mixtures. Figs(2,3) show that the adding of silica fume 3%, 6% and 9% substitute 13%,16.4% and 22.8% from strength lost by substitution of CKD by40% While those percentage increasing to be 30.43%, 44%, and 51.61% As shown in Fig(4,5) when the substitution was by sand, the big difference between the effect of silica fume with CKD and sand is due to the surface area which increasing in the mixtures of CKD than the mixtures of sand, then decrease the bond between particles and consequently decrease the strength The results show that the substitution of both CKD or Sand by 40%had the big amount of strength gained by adding silica fume.

Conclusion

- Adding Silica Fume to concrete mixes increases Compressive strength
- Concrete mixtures containing replacement percentage of CKD (10% -60%) had reduction in compressive strength about (5% - 37%) (table 9)
- Concrete mixtures containing replacement percentage of sand (10% -60%) had reduction in compressive strength about (1.4% -40.2%) see table (9).
- Using of silica fume in concrete mixtures partially substitute the lost strength when CKD or sand substitute cement see fig (7).
- Silica fume is more effective when using in mixtures had cement replacement with sand than mixtures had cement replacement with CKD.
- 40% substitution for both CKD or sand gives the optimum gained strength with different values of silica fume compared with different percentage of substitution. (See fig 7).

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