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Design of High Strength Concrete (HSC) Using North Sinai Materials

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Abstract

The use of high strength concrete in building systems is increased all over the world. This research presents the production of high strength concrete using local materials available in north Sinai area. All concrete ingredients (cement, water, fine and coarse aggregates in addition to admixtures) were subject to the requirements of the Egyptian standard specifications. Compressive strength, indirect tensile strength, flexural strength, and permeability tests were conducted on the concrete. In this research, 27 concrete mixes were made with cement content 400,450 and 500 Kg/ m³. One type of Beir El-bd sand is used as fine aggregate and three types of coarse aggregates basalt, dolomite and gravel are used in high strength concrete mixtures. Silica fume was used with a dosage of (0, 10, 15) % of cement content, and also high water range reducer superplasticizer with a dosage of (0 and 3) % of the binder content. To achieve compressive strength greater than 500 kg/cm² at the age of 28 days. As a result, concrete mix containing a dolomite 15% silica fume with 3% superplasticizer produced a compressive strength of 950 kg/cm² and low permeability of $1.6x10^{-9}$ cm³/sec. The use of lower amount of cement content, silica fume and superplasticizer gives lower strength and high permeability. Analyzing the results of this research produce a design that describes compressive strength-silica fume relationship curves and compressive strength-superplasticizer content relationship.

Key words:-high strength concrete, silica fume, compressive strength, indirect tensile strength, flexure strength.

1. INTRODUCTION

Sinai Peninsula runs along the north-east of Egypt with a total area of about 61,000 square Kilometers. The importance of North Sinai mountains to construction, such as granite, basalt, limestone, and crushed stone and gravel in addition to the presence of sand which is used in the work of concrete in Sinai. [1]

The study area extends along North Sinai Peninsula plain which is considered an integral part of the Mediterranean Sea. This paper leads to a better understanding of the effect of aggregate type on the mechanical behaviour of high strength concrete and a trial to produce high strength concrete from these available materials.

ACI committee 363 on HSC, in its 1997 report has specified compressive strengths for design of 6000 psi (41 MPa) or greater, but for the present time, considerations shall not include concrete made using exotic materials or techniques. [2]

The FIP/CEB defines HSC as "a concrete having a minimum 28-day compressive strength 60MPa". Due to its fine microstructure, HSC possesses different mechanical properties compared to normal strength concrete. [3] In the 1950's, concrete with a compressive strength of 5000 Psi (34 MPa) was considered high strength. In the early 1970's, 9000 Psi (62 MPa) concrete was produced. More recently, compressive strengths approaching 20,000 Psi (138 MPa) have been used in cast-in-place buildings. [4]

The high compressive strength can be used advantageously in compression members such as columns and piles. In columns, the reduction in size will lead to reduced dead load and subsequently will reduce total load on the foundation system. [5]

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The map given in fig.(1) shows the locations of dolomite rocks in north Sinai.[1] There are dolomite rocks as show in fig 1 with large quantity, either alone or associated with layers of limestone and rock. Dolomite rocks are characterized by high resistance to severe weather, pressure, and the proportion of the magnesium oxide from 13% to 20.5%. Dolomite rocks are used to pave roads and in concrete and stone construction. [1]

Although some design specifications have addressed the use of HSC, many have implicitly or explicitly placed restriction on its use, primarily because of limited research data. [6]

Extensive experimental investigations by Entroy and Shacklock [7] have indicated that in high strength concrete mixes, workability, type and maximum size of aggregate and the strength requirements, influence the selection of the water/cement ratio. The increase of tensile strength affects the increase of compressive strengths. There is a decrease, however, in the ratio of tensile to compressive strength as compressive strength increases. [8]

French et al. (1993) [9]observed in their study that 100 x 200 mm cylinders tested showed 6 percent higher strength than that of their companion 150 x 300 mm cylinders. Aïtcin et al. (1994) [10] reported that larger cylinder sizes gave rise to lower apparent compressive strength, and that compressive strength is not sensitive to cylinder size for very high strength concrete. The relationship between the ratio of splitting tensile strength to compressive strength (ftsp/fc) and cylinder compressive strength (fc), which are applicable to concrete at early ages (12 hours and longer) as well as very high strength concrete up to 1224 kg/cm² are influenced by the level of concrete strength. [11]

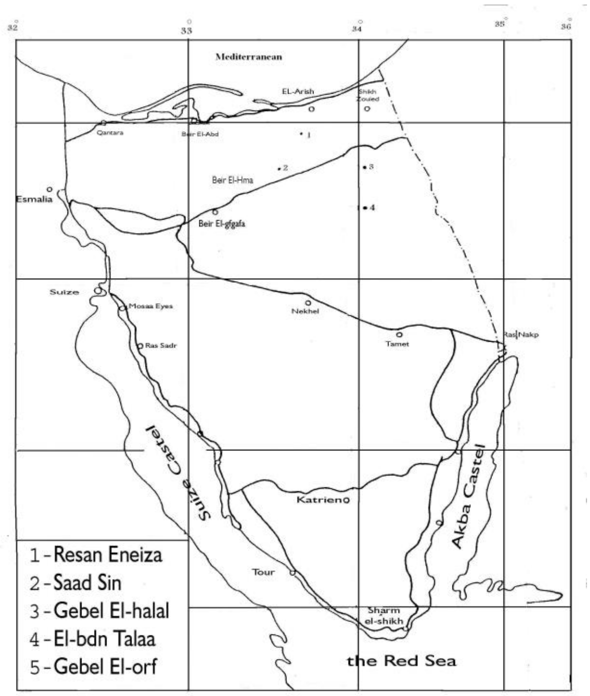

Fig 1: locations of dolomite rocks in the Sinai

The State–of –the report on high-strength concrete [2] reported that silica fume has been used in high-strength concretes for structural purposes.

There is no exact method for determining the required superplasticizer dosage. When achieving strength considered as the primary criterion, it should be with the lowest water-cement ratio, and the highest superplasticizer rate. [4]

2. Experimental work

Experimental work using local resources of North Sinai materials was conducted to produce high strength concrete.

Figure 2 shows the difference between two types of North Sinai fine aggregates and the results indicated that Beir El-Abd sand is rougher than El-Arish sand and both are in the range of the specifications, according to the Egyptian code of concrete laboratory and tests, [12] and ASTM C136 specifications [13]:

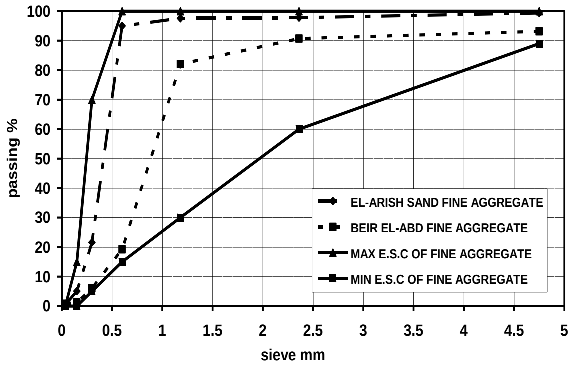

Figure 2: sieve analysis curves of fine aggregates in North Sinai

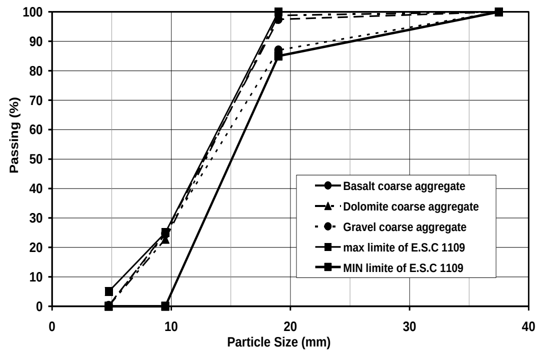

Fig 3 the particle size distribution of three types of North Sinai course aggregates.

The specific gravity was determined according to ASTM [14] and list in Tables (1, 2).

Table 1: specific gravity of coarse aggregate according to Egyptian standards:

North Sinai coarse aggregate	Average	Egyptian standards
Dolomite	2.70	2.6-2.7
Basalt	2.66	2.6-2.8
Gravel	2.60	2.5-2.7

Table 2: the specific gravity of North Sinai fine aggregate according to Egyptian standards:

Fine Aggregate	Specific gravity	Egyptian code
El-arish sand	2.55	2.5-2.75
Ber El-abd sand	2.57	2.5-2.75

Table 3: mix proportion using different types of North Sinai aggregates with W/C 0.3, cement content ٥٠٠ kg/m^3.

Batch no	Coarse aggregate type	Coarse aggregate kg/m^3	sand kg/m^3	%SF	%SP	Slump (cm)
P1	Basalt	1223.7	578.12	0%	0%	11
P2	Basalt	1158.5	547.3	10%	3%	٩
P3	Basalt	1146.4	541.6	15%	3%	٨
P4	Dolomite	1235.3	584.39	0%	0%	٥
P5	Dolomite	1170	552.7	10%	3%	٩
P6	Dolomite	1157.8	547	15%	3%	٧,٥
P7	Gravel	1237	583	0%	0%	٥,٥
P8	Gravel	1081	510	10%	3%	٩
P9	Gravel	1159	546	15%	3%	٨

Table 4: mix proportion using different types of North Sinai aggregates with W/C 0.3, cement content 45٠ kg/m^3.

Batch no	Coarse aggregate type	Coarse aggregate kg/m^3	sand kg/m^3	%SF	%SP	Slump (cm)
P10	Basalt	1278.31	603.9	0%	0%	١١
P11	Basalt	1219.7	576.2	10%	3%	٨
P12	Basalt	1208.8	571.1	15%	3%	٨
P13	Dolomite	1290.45	610.5	0%	0%	١٢
P14	Dolomite	1231.8	582	10%	3%	٦,٥

P15	Dolomite	1221	576.8	15%	3%	٧,٥
P16	Gravel	1292.21	607.86	0%	0%	١٢
P17	Gravel	1152.4	543	10%	3%	٨
P18	Gravel	1222	575.7	15%	3%	٨

Table 5: mix proportion using different types of North Sinai aggregates with W/C 0.3, cement content 40٠ kg/m³.

Batch no	Coarse aggregate type	Coarse aggregate kg/m³	sand kg/m³	%SF	%SP	Slump (cm)
P19	Basalt	1333	630	0%	0%	5
P20	Basalt	1285.3	607.2	10%	3%	١٤
P21	Basalt	1271.2	600.5	15%	3%	١٣
P22	Dolomite	1345	635.6	0%	0%	٦
P23	Dolomite	1298.1	614	10%	3%	١٥
P24	Dolomite	1283.8	606.5	15%	3%	١٤
P25	Gravel	1347.5	634.9	0%	0%	٦
P26	Gravel	1299.3	612.2	10%	3%	١١
P27	Gravel	1285	605.5	15%	3%	٩

According to Egyptian code [12] the abrasion resistance of coarse aggregates in los Angeles machine doesn't exceed about 20% for gravel and 30% for crushed stone (dolomite and basalt). A Sample of aggregate retained on No 9.5mm sieve is placed inside a rotating steel drum .The test results of north Sinai coarse aggregates are shown in the following table.

Table 6: abrasion resistance percentage of coarse aggregates:

North Sinai coarse aggreagte	abrasion resistance%
Dolomite	0.097%
Basalt	0.069%
Gravel	0.017%

As illustrated in Table 7, the mechanical properties of north Sinai cement shows the compressive strength, initial and final setting time used in this research.

***Table 7: Mechanical properties of Sinai cement*:**

Test		Sinai cement	Egyptian specifications
Compressive strength kg / cm2	7day	410:430	270
	28day	530:560	360
Initial setting time(min)		110:150	>45
Final setting time(hr)		2.5:3	<10
Fineness(gm/cm²)		3300±100	>2500

The coarse aggregate was washed, the fine and coarse aggregate moisture contents were measured prior to mixing. superplasticizer was considered in proportioning, with mix water cement ratio 0.30 attained for the next concrete mixes. The curing ages mixtures to produce high strength are 3, 7, and 28 days for compression strength, curing ages 7 and 28 days for the indirect tensile strength and Curing ages 28 and 56 for the flexure strength .

According to ASTM C192 [15] ,the test specimens for the high strength concrete were (15x15x15) concrete cubes, (15x30) cylinders, (10x 10 x 50 mm) beams.

Permeability test for the concrete mixtures were performed. Table (8) shows the results of permeability test with dolomite, basalt and gravel. permeability test were conducted to Batches P3,P6,and P9 using (500 kg/m³ cement content, 15% silica fume (S.F) , 3% superplasticizer (PC) of cement content shown in Table (4).

Table 8: result of permeability

Mix no	Coarse aggregate	K(cm/sec)
P3	Basalt	$1.2x10^{-12}$
P6	Dolomite	$1.35x10^{-10}$
P9	Gravel	$1.12x10^{-11}$

3. Results

3.1- The mechanical properties of the concrete mixes were shown in table (9,10,11)

high strength concrete mixtures results using Beir El-Abd sand and North Sinai coarse aggregates with water cement ratio (w/c) =0.3, cement content 400,450 and 500 kg/m², silica fume, superplasticizer as a percentages with cement content as shown in experimental work are shown in Tables (3,4 and 5).

Table 9: results of the mix proportion using different types of North Sinai aggregates with W/C 0.3, and cement content 50٠ kg/m³.

Batch No	Compressive strength (kg/cm²)			Indirect tensile strength (kg/cm²)		Flexure strength (kg/cm²)	
days	3	7	28	7	28	28	٥٦
P1	260	297	400	38.8	48	43	47
P2	475	590	780	56	62	80	102
P3	522	641	860	64	73	82	104
P4	253	331	484	44.7	54	44	49
P5	510	640	865	68	74	92	100
P6	529	702	945	69	83	96	108
P7	206	278	408	36.5	44	39	44
P8	384	540	710	52	54	56	74
P9	398	596	803	55	60	66	83

Table 10: results of the mix proportion using different types of North Sinai aggregates with W/C 0.3, and cement content 45٠ kg/m³.

Batch No	Compressive strength (kg/cm²)			Indirect tensile strength (kg/cm²)		Flexure strength (kg/cm²)	
days	3	7	28	7	28	28	٥٦
P10	225	307	440	35.8	43.9	40.4	43.4
P11	474	575	753	48.1	58	76.8	94.8
P12	497	616	825	55.9	65.1	79.2	95.4
P13	240	320	470	41.7	50.2	40.7	46.4
P14	495	626	795	66.5	67.9	81	96
P15	502	675	855	67.9	73.2	82.8	98
P16	195	267	395	32.5	40.3	36.5	40.1
P17	435	545	689	45	50	53	58.6
P18	453	580	719	46	52	53.1	59.1

Table 11: results of the mix proportion using different types of North Sinai aggregates with W/C 0.3, and cement content 40 ٠ kg/m³.

Batch No	Compressive strength (kg/cm²)			Indirect tensile strength (kg/cm²)		Flexure strength (kg/cm²)	
days	3	7	28	7	28	28	٥٦
P19	195	265	364	22.6	34	35	41.2
P20	390	507	685	36.8	47.5	48	54
P21	426	553	692	45.3	56.6	52.8	58.8
P22	189	280	385	34	40.5	40.3	42.3
P23	390	537	691	42.5	51	52	72
P24	383	476	714	44.6	53.8	51.2	57.9
P25	175	240	340	19.8	29	28	36
P26	340	471	630	34	38.9	35.10	42
P27	371	571	618	38.2	46.7	40	50

3.2-Results of the cubes, cylinders, and flexure beam strength.

Curves show that compressive strength values increased due to cement content and curing ages increase. As shown in Figure (5) for 28 days curing age a(945 kg/cm²) strength value in P4 using dolomite coarse aggregates is higher than the value (860 kg/cm²)in P1 using basalt coarse aggregates as shown in Figure (4). But in P7 using gravel coarse aggregates value of the strength (803 kg/cm²) is lower than values in P1, P4 as shown in Figure (6).

Also, indirect tensile and flexure strength values in Batch (4) are (83) and (108) kg/cm²) respectively using dolomite which is higher than the others.

The results indicated that the mechanical properties of dolomite north Sinai coarse aggregates is better than both basalt and gravel. Using the same cement content 500 Kg/m³, w/c=0.3, 15% silica fume and superplasicizer with Beir El-Abd sand and changing cement content from 500 to 450 and 400 Kg/m³,with w/c=0.3, 15% silica fume, superplasicizer with Beir El-Abd sand gave the same results shown in tables 10,11.

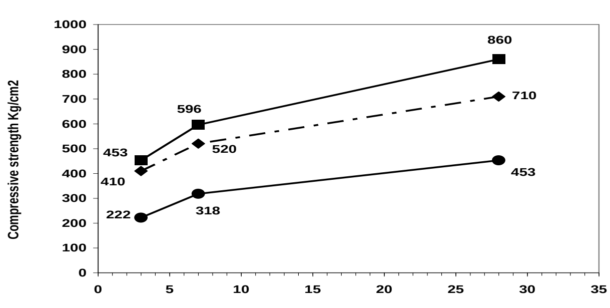

Fig 4: Relation between compressive strength & curing age at 3,7,28 days W/C=0.3, CC=500 Kg/m³ of Basalt with Beir El-Abd sand

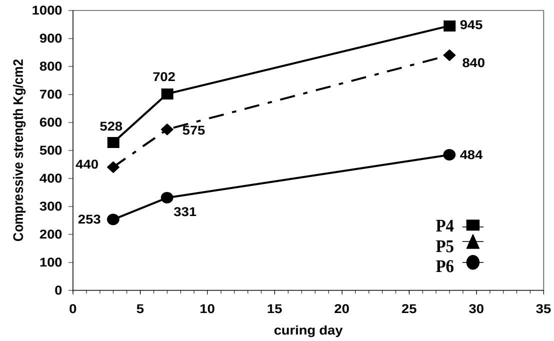

Fig 5: Relation between compressive strength & curing age at 3,7,28 days W/C=0.3, CC=500 Kg/m³ of Dolomite with Beir El-Abd sand

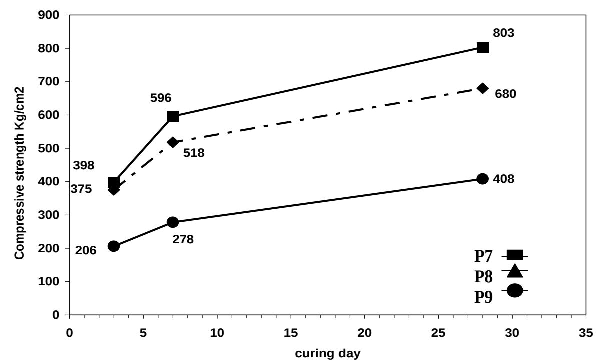

Fig 6: Relation between compressive strength & curing age at 3,7,28 days W/C=0.3, CC=500 Kg/m³ of Gravel with Beir El-Abd sand

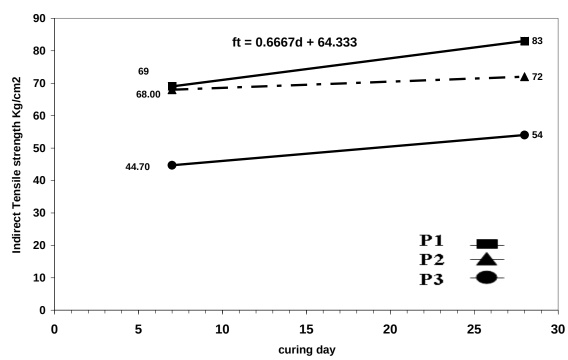

Fig 7: Relation between Indirect Tensile strength &curing age at 7, 28 days W/C=0.3,CC=500Kg/m³ of Dolomite with Beir El-Abd sand

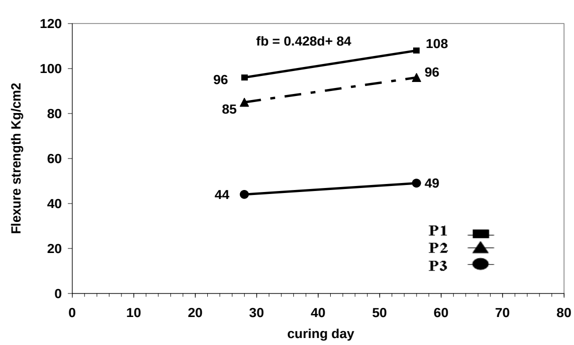

Fig 8: Relation between flexure strength &curing age at 28, 56 days W/C=0.3, CC=500 Kg/m³ of Dolomite with Beir El-Abd sand

Figures 9.10.11and 15show relation between compressive strength and silica fume with cement content 500,450,and400 Kg/m³ respectively .The results show the effects on compressive strength of using different amounts of cement content, silica fume, and water cement ratio in high strength concrete using north Sinai materials. The curves that are shown are typical of what may be expected. The very important point in these figures are:

The ratio of 3-day or 7-day strength to 28-day strength is reasonably consistent, regardless of the 28-day strength achieved. The ratio of 15% silica fume content to cement ratio achieve a higher strength concrete in dolomite than in basalt and gravel aggregates. It is clear that the results of curves are close to each other of basalt and gravel in Figure 9.while the results of curves are close to each other of dolomite and basalt in figure 10 and 11 respectively.

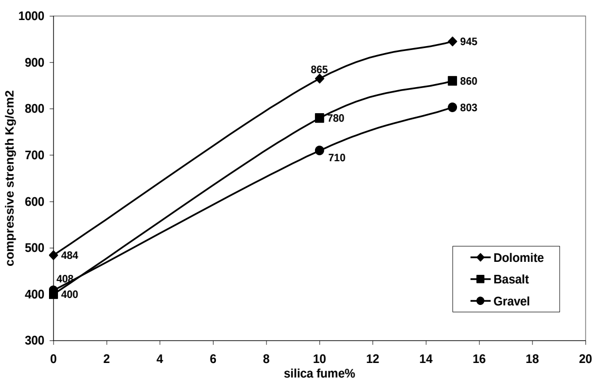

Fig 9: Relation between compressive strength and silica fume at 28 days W/C=0.3, 3% superplastisizer and CC=500 Kg/m³ with Beir El-Abd sand

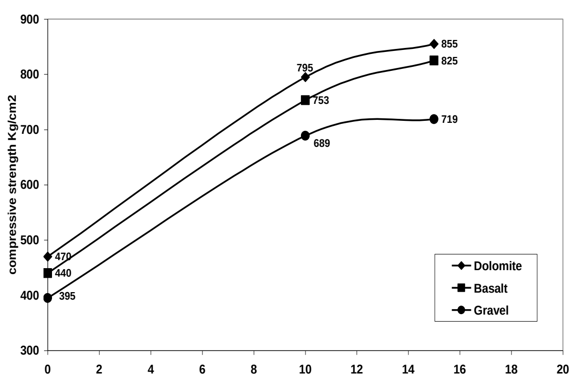

Fig 10: Relation between compressive strength and silica fume at 28 days W/C=0.3, 3% superplastisizer and CC=450 Kg/m³ with Beir El-Abd sand

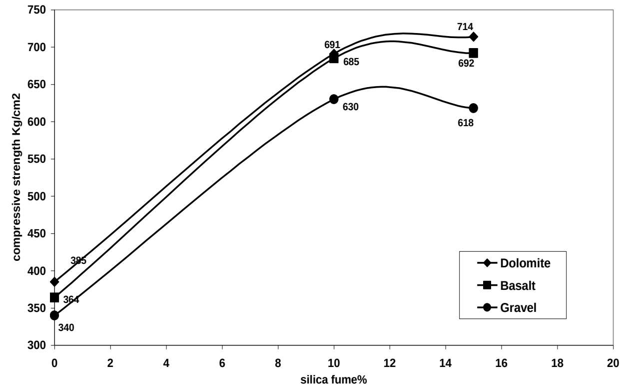

Fig 11: Relation between compressive strength and silica fume at 28 days W/C=0.3, 3% superplastisizer and CC=400 Kg/m³ with Beir El-Abd sand

In Figure 12, 13 and 14 it is observed that dolomite gave higher compressive strength, indirect tensile strength and flexure strength than basalt and gravel. The indirect tensile strength is affected by the changes of the compressive strength. Indirect tensile strength and compressive strength in mixtures P3, P6 and P9 is higher than other mixtures as shown in the figures. On the other hand, the effect of compressive strength, on indirect tensile strength and flexure strength using 500 Kg/cm^2 cement Content in mixtures from P1 to P 9 is more than mixtures using 450 Kg/cm^2 and 400 Kg/cm^2 cement content.

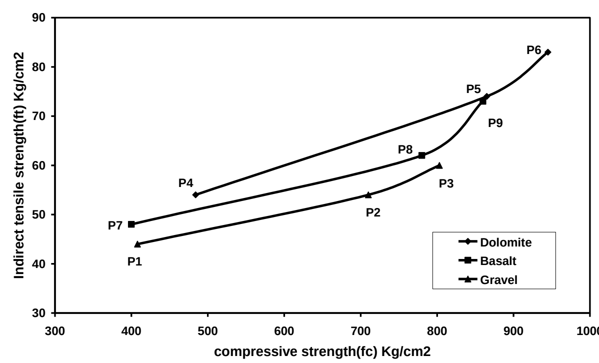

Fig 12: Relation between compressive strength and indirect tensile strength

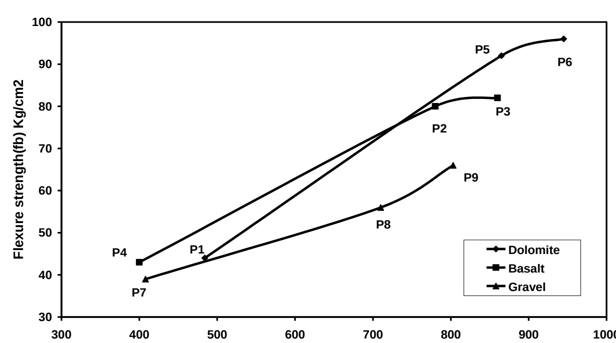

Fig 13: Relation between compressive strength and flexure strength

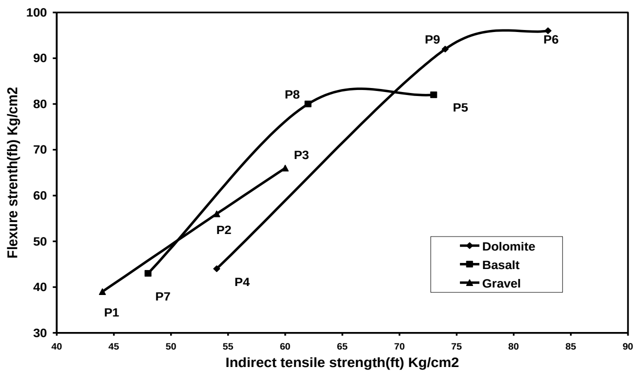

Fig 14: Relation between indirect tensile strength and flexure strength.

3.3- HSC design procedure using north Sinai materials

Design the concrete mix required for high strength concrete using North Sinai materials:

Step (1) Type I cement having a bulk specific gravity of 3.15 is used.

Step (2) to determine the average compressive strength of the concrete mix to be designed:

applying the control factors to the minimum compressive strength .The required average strength used for selection of concrete proportion from the equation [12]:

Fcr= (fcu+98)/0.90 kg/m^3 …………… (5.1)

Then find the suitable cement content from Fig 15 when using Beir El-Abd sand

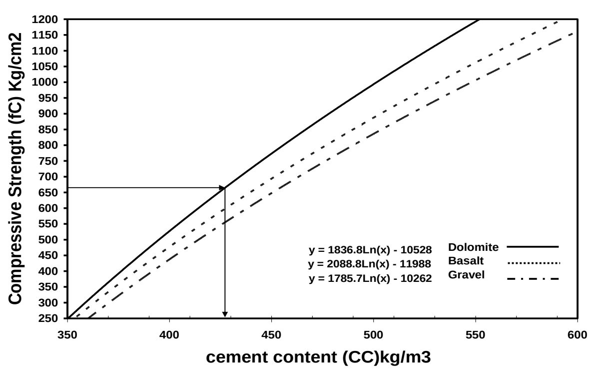

Fig 15: relation between compressive strength using Beir El-Abd sand and cement content 500Kg/m³

Step (3) choose the w/c ratio to be 0.3 to achieve a high strength concrete using North Sinai materials

Step (4) select the suitable amount of silica fume percentage using relation between compressive strength and cement content as shown in Figures 16,17 and 18 as follows:

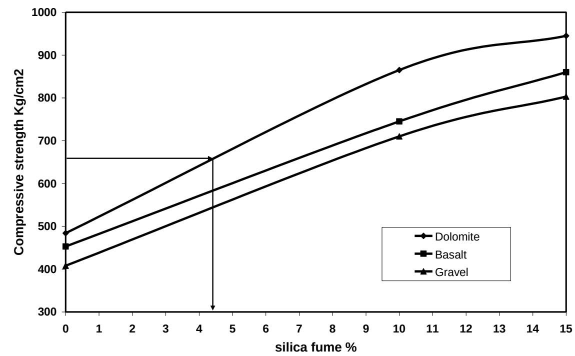

Fig 16: Relation between compressive strength and silica fume, CC=500 Kg/m3,w/c=0.3 Beir El-Abd sand

Steps (5) select the suitable amount of super plasticizer percentage.

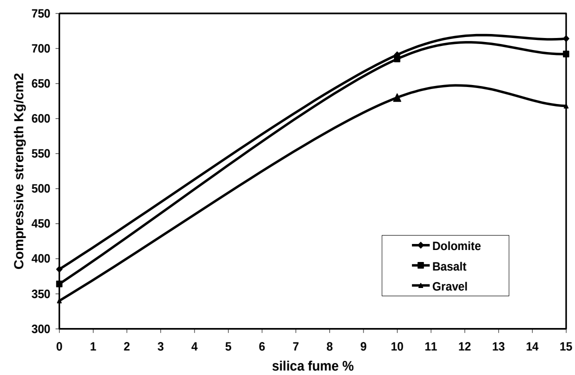

Fig 17: Relation between compressive strength and silica fume, CC=450 Kg/m3,w/c=0.3 Beir El-Abd sand

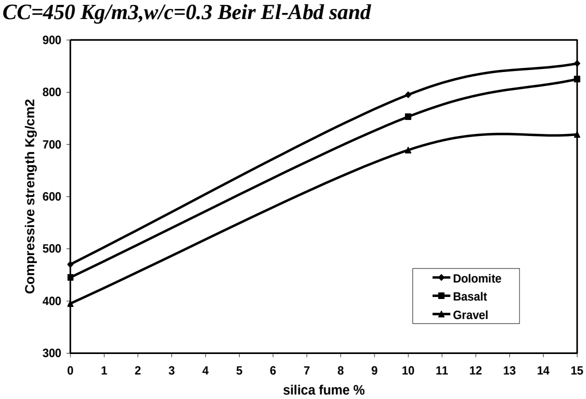

Fig18: Relation between compressive strength and silica fume, CC=400 Kg/m3,w/c=0.3 Beir El-Abd sand

Step (6) it is suggested that sand content is to be calculated by absolute volume method.

Table 12: Volume of coarse aggregate per unit volume of concrete

Maximum size of aggregate (cm)	Volume of dry-roded coarse aggregate per unit volume of concrete for different finesse modulus of sand		
C.A	Dolomite	Basalt	Gravel
Specific gravity	٢,٧	٢,٦٦	٢,٦
1	0.46	0.57	0.59
1.25	0.55	0.64	0.66

Example, High strength concrete is to be proportioned for a high rise structure that will not be exposed to freezing and thawing using North Sinai materials. The designer did not require any air entrained contain in concrete.

(a) Assume 600 kg/cm² concrete strength required, substituting in Equation 5.1, the average strength used is 665 kg/cm² as step 2. The cement content is 4٢٥ Kg/m^3 obtained from Fig 15

(b) A water cement ratio of 0.3 w/c will be used in the concrete mix design and equals to 156 kg/m3.

(c) Using Figure 16 to get 4.5% silica fume and 2% super plasticizer of cement content, they are equal to 19.12 and 8.5 kg/m^3 respectively.

(d) Job conditions indicate that dolomite coarse aggregate with a maximum size of 2.5 cm to be 0.67 cubic meter on dry rodded basis per cubic meter of concrete. Therefore, the coarse aggregate content is 1000x0.67=670 kg/m^3 The Beir El-Abd sand fine aggregate is natural sand of 2.5 specific gravity.

(f) The quantities of cement, fly ash, coarse aggregate, non-entrained air, and water having been established, the following absolute volumes of ingredients are:

(425/3.15)+ (19.12/2.20) + (8.5/1.1) + (670/2.7) + (Ws/2.5) + (152/1) =1000 ………………. (1)

Solid volume of sand required = m^3, so required weight of dry sand = 448.52 x 2.5= 1121.30 kg/m^3

4. CONCLUSION

1. Effect of cement content and W/C ratio in HSC

The study shows that when the cement content was increased, the compressive strength can reach (950 Kg/cm^2) with dolomite coarse aggregates.

2 Effect of silica fume ratio in HSC

The concrete containing 15% silica fume produces higher compressive than that 10% silica fume at 3, 7 days to 28 days curing age. The incorporation of silica fume in mixes resulted in finer pore structure thus produces low permeability concrete as that results indicated.

3 Effect of coarse and fine aggregate types in HSC

A series of tests were carried out to study the compressive, indirect tensile and flexure properties of HSC. The test results indicate that dolomite coarse aggregates represent the best of north Sinai coarse aggregates within the types studied, as long as silica fume and super plasticizer, are used.

5- Recommendations

Further testing and studies on North Sinai aggregate concrete is highly recommended to indicate the strength characteristics of North Sinai aggregates for application in high strength concrete.

It is recommended that testing can be done on concrete slabs, beams, and more trials with different particle sizes of North Sinai aggregates and percentage of replacement of North Sinai aggregates are recommended using steps and curves design in results sheet to get different outcomes and higher strength characteristics in the N.S aggregate concrete.

NOTATION

HSC- High strength concrete
ACI – American concrete institute
FIB/CEB-
W/c – water/cement
Mpa – Mega Pascal
E.S.C – Egyptian standard code
Psi- pound/square inch
SF – silica fume
SP- superplastcizer
ASTM- American Society for testing and materials
PC-PLAST CRETE superplastcizer.
CC- cements content
Fcr -The required average strength.
Fcu -Minimum compressive strength.
Fc-compressive strength
Ft-indirect tensile strength
Fb- flexure strength

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