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Research paper

Influence of Percentage Replacement of Metakaolin on Different Concrete Types Exposed to Internal Sulphate Attack

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Abstract

This research presents an experimental investigation on the influence of metakaolin replacement percentage upon some properties of different concrete types. Three types of concrete were adopted (self- compacted concrete, high performance concrete and reactive powder concrete) all of high sulphate (SO_3) percentage from the fine aggregate weight, 0.75%.
Three percentages of metakaolin replacement were selected to be studied (5, 7 and 10) %. Three types of concrete properties (compressive, flexural and splitting tensile strength) were adopted to achieve better understanding for the influence of adding metakaolin..
The output results indicated that the percentage of metakaolin had a different level of positive effect on the compressive strength for both including and excluding of internal sulphate attack. This effect reached at 28 days of curing to (11.86, 10.22 and 4.75) % in case of excluding sulphate attack and to (13.82, 11.47and 6.53) % in the other case for SCC, HPC and RPC respectively. It can be concluded that the effect of metakaolin in both SCC and HPC are more influence than in RPC. Splitting and flexural strength have showed a similar behavior, flexural strength increased by (15.38, 9.42 and 5,84) % at age of 28 days when the sulphate attack is excluded, while it was (14.02, 10.66 and 4.28)% in case of sulphate attack included for SCC,HPC and RPC respectively. The response of splitting tensile strength for both including and excluding of sulphate attack reached to (13.03, 12.95 and 9.17) % and (16.88, 10.33 and 6.74) % respectively for SCC, HPC and RPC.

Keywords: *High performance concrete, internal sulphate attack, metakaolin, reactive powder concrete and self-compacted concrete.*

1. Introduction

The response among sulfate and bond glue mixes, for example, mono sulfate, portlandite, and C-S-H gel is signified as sulfate assault. Gypsum, Ettringite and Thaumasite are the principle results of this response while destabilization of the C-S-H gel might be another outcome of this response.
Ihab S., 2017, has been Researched the outside and interior impact of sulfate on ordinary and elite cement. The exploratory investigation was done utilizing two sorts of concretes, sulfate opposition and customary Portland bond of 10% smoke silica and two kinds of sand of standard SO3 = 0.2% and non-standard SO3 =1.3%. The outcomes demonstrated that the hurtful impact of the inward sulfate assault was diminished if there should be an occurrence of utilizing sulfate opposition bond and the interior sulfate assault was obvious at early ages till 90 days [1].

Nothing M. furthermore, Samaa H., 2016, have been examined the obstruction of elite cement to inward sulfate assault utilizing two kinds of bond sulfate opposition and normal Portland concrete with two mineral admixture as a fractional substitution by weight of bond, for example, high reactivity metakaolin (10%) and silica seethe (8 and 10)% for the two sorts of concrete. The outcomes called attention to that the lower decrease in a few properties of bond was sulfate opposition concrete, and the most decrease in compressive quality was seen at age 90 days for normal Portland bond blends and 28 days for sulfate obstruction concrete blends and this that the utilization of high reactivity metakaolin demonstrated preferred outcomes over silica seethe [2].
Tariq S. et al, 2006, has considered the impact of inner sulfate assault on the conduct of elite cement containing metakaolin as a pozzolanic material utilizing four sulfate content in fine total (0.5,1.5,2.0 and 2.5)%. Testing the compressive quality, part quality and ultrasonic speed showed that the quality decrease was evident at early ages (under 28 days) for both superior and conventional cement, yet at later ages (over 28 days) the elite solid decrease diminished while the decrease in customary cement expanded [3].
Anusiya M. what's more, Oviya S., 2017, have made a relative between receptive powder concrete and high quality cement. The sturdiness of the embraced solid sorts was considered by estimating the loss of solid weight after outside sulfate assault to establish out that the receptive powder concrete has higher solidness than high quality cement. Different properties, for example, compressive quality, flexural quality and youthful modulus were additionally considered, every one of these properties indicated better outcomes for responsive powder concrete contrasted with high quality cement [4].
Esam M., 2013, has researched the impact of inward sulfate assault on some mechanical properties of self-compacted cement, for example, compressive quality, flexural quality and part elasticity at (28) days and (60) days individually and contrasted them and those of reference ordinary solid blend. Three sulfate content in fine total (0.5, 1, and 1.5)% was utilized. The outcomes demon-

strated that expanding the size of SO3 around (0.5-1.5)% by weight of sand caused a decrease in the compressive quality, part rigidity and modulus of break by (10-26)%, (9-29)% and (14-35)% at (28) days separately, while at (60) days of restoring they diminishes by (12-51)%, (17-30)% and (23-43)% individually [5].
Hadeel K., 2017, was exhibited an investigation on the impact of utilizing two sorts of normal Portland bonds of various compound arrangement on a few properties of self-compacted concrete. A concrete substitution of high reactivity metakaolin by (5, 10 and 15)% was considered in this exploration. It was reasoned that oneself compacted concrete blends made by Saudi Arabia Common Portland bond with a synthetic organization C3A=7.02% demonstrates higher protection from inside sulfate assault than blends with Tasluja conventional Portland concrete of a concoction sythesis C3A=4.13%. The outcomes likewise shown that the SCC blends containing 15% high reactivity metakaolin indicates higher protection from inner sulfate assault [6].

2. Research significance

The point of this examination is to discover the impact of utilizing distinctive level of metakaolin as an incomplete substitution by weight of concrete (5, 7 and 10)% on some mechanical properties of SCC, HPC and RPC with a researched level of sulfate content in fine total (0.75)%. This rate has accomplished by including common gypsum as a fractional substitution by weight of fine total at (7, 28, 60, 90 and 120) days separately.

3. Materials

Normal Portland bond (OPC), which is made in Iraq known as (Tassloja) has been utilized in this examination, the physical and substance properties of the utilized concrete were displayed in Table 1 as indicated by Iraqi determination IQS NO. 5/1984 [7] and ASTM C150 2007 [8]. Two sorts of regular fine total were utilized in this investigation. The first was confirms to zone two and it was utilized in all HPC and SCC blends, the reviewing of the sand is inside the Iraqi detail IQS NO.45/1984 [9] and ASTM C33 2003 [10]. Table 2 demonstrates the reviewing, physical properties and sulfate substance of the utilized fine total. The second sort of fine total was of normal fine total with an explicit gravity of 2.59 and a grain estimate appropriation extending from (150 µm) to (600 µm), this sort was utilized in all receptive powder concrete blends.
The regular gypsum was of an equivalent degree as the utilized fine total. The gypsum was utilized as a halfway supplanting by weight of sand with restricted rate to expand the measure of the inward sulfate in fine total from 0.26% to 0.75%. The concoction piece of the utilized gypsum is recorded in Table 3.
A most extreme size of (10 mm) Pounded rock has been utilized as a coarse total in HPC and SCC blends. The reviewing and physical properties are inside the limit determined of Iraqi standard IQS No.45/1984 [9], as appeared in Table 4. The water utilized for both blending and relieving for every solid kind was Faucet water.
High responsive metakaolin delivered by consuming mud at temperatures went between (700 – 900) °C. In this examination, the locally accessible mud was scorched in consuming furnace at a temperature of 700°C for two hour at that point left to chill off at room temperature. The Physical properties and substance structure of HRM that fulfilled to the ASTM C 618 – 08 [11] are outlined in Table 5. It has been utilized as a fractional substitution of concrete in all the blends at various rates. As to smolder, Table 6 demonstrates the physical properties and synthetic arrangement which accommodates the necessities of ASTM C1240-03[12].
The kind of superplasticizer which is utilized as a concoction admixture in this examination seemed to be (SikaViscoCrete - 5930) as per ASTM C494-05[13]. The properties of the utilized superplasticizer are appeared in Table 7.

Table 1: Cement properties

Abbreviation		Results	Limit of Iraqi Specification No. 5 [7]	Limit of ASTM C150 [8]
Chemical properties (%)	CaO	62.5	-	
	SiO_2	21.5	-	
	Al_2O_3	4.2	-	
	Fe_2O_3	3.95	-	
	SO_3	2.36	$\leq$ 2.8 If $C_3A \geq 5\%$	$\leq$3.0 If $C_3A \leq 8\%$
	MgO	2.47	$\leq$ 5.0 %	$\leq$ 6.0 %
	L.O.I.	2.84	$\leq$ 4.0 %	$\leq$ 3.0 %
	I.R.	0.56	$\leq$ 1.5 %	$\leq$ 0.75 %
	L.S.F	0.77	0.66-1.02	
Bogue's equations	C_3S	57.11	-	-
	C_2S	18.65	-	-
	C_3A	4.44	-	-
	C_4AF	12.02	-	-
Setting time (Vicat's method) Initial setting Final setting		1:32 5:53 hrs.:min	$\geq$ 45 min $\leq$ 10 hrs.	$\geq$ 45 min $\leq$375min
Compressive strength (MPa) 3 days 7 days		16.9 25.5	$\geq$ 15 $\geq$ 23	$\geq$ 12 $\geq$ 19
Blaine surface area (m^2/ kg)		322	$\geq$ 230	$\geq$ 280
Soundness (Auto clave Method) (%)		0.4	$\leq$ 0.8	-

Table 2: Properties of fine aggregate

Tests		Passing (%)	Iraqi specifications No.45/1984 (Zone 2)[9]	ASTM specification C33-[10]
Sieve size (mm)	10	100	100	100
	4.75	92	90-100	95 -100
	2.36	89	75-100	80 – 100
	1.18	65	55-90	50 – 85
	0.6	51	35-59	25 – 60
	0.3	24	8-30	5 – 30
	0.15	6	0-10	0 – 10
Material finer than 0.075mm		2.6	$\leq$ 5	$\leq$5
Sulphate SO_3 (%)		0.26	Max. 0.5	-
Absorption (%)		1.12	-	-

Table 3: The chemical properties of the gypsum

Compound Composition Percent %	Compound Composition Percent %
SiO_2	8.91
R_2O_3	2.04
CaO	31.65
MgO	0.87
SO_3	42.4
I.R	6.78

Table 4: Properties of coarse aggregate

Sieve size (mm)	Passing%	Limits of Iraqi specification. No.45/1984 [9]
37.5	100	100
20	100	95-100
10	52	30-60
4.75	6	0-10
Absorption	0.5%	-
SO_3	0.06%	$\leq$ 0.1%
Specific gravity	2.69	-

Table 5: Physical properties and chemical composition of high reactive metakaolin

Oxide Composition	Oxide content %	Pozzolan class N ASTM C618-03[11]
SiO_2	54.67	Σ = 89.3% Min. 70%
Al_2O_3	33.11	
Fe_2O_3	1.52	
MgO	0.35	
CaO	0.42	
SO_3	0.19	Max. 4%

Na_2O	0.73	
L.O.I	3.78	Max. 10%
Physical properties		
Fineness (Blaine)		1120 m²/kg
Specific gravity		2.59
Physical form		Powder

Table 6: Physical properties and chemical composition of silica fume

Oxide Composition	Oxide Content %	ASTM C1240-03 [12]
SiO_2	92.73	Min. 85%
Al_2O_3	0.18	
Fe_2O_3	0.03	
MgO	0.02	
CaO	0.72	
SO_3	0.42	
K_2O	0.07	
L.O.I	3.4	Max. 6%
Physical properties		
Fineness (Blaine)		15000 m²/kg
Specific gravity		2.12
Physical form		Powder
Color		Gray

Table 7: Typical properties of superplasticizer (SikaViscoCrete -5930)

Form	Viscous liquid
Basis	Aqueous solution of modified polycarboxlate
Appearance	Turbid liquid
Relative density	1.08 g/1t.±0.005

4. Mix design

A high performance concrete with a compressive strength of 50 MPa at 28 days has been designed according to the American Method ACI 211.4R-93 [14] as shown in Table 8. The adopted mix proportion was (1:1.23:2.06) and the optimum dosage of superplasticizer (SikaViscoCrete -5930) was 1.2 liter for each 100 kg of cement which was prevailed from several trail mixes.

The self-compacted concrete mix used in this study was designed accordance to EFNARC 2005/ SF1 [15]. The mix proportion is presented in Table 8. The materials contents are revised after gaining acceptable self-compatibility by assessing fresh concrete tests.

The RPC that's considered in this study was prepared by the following ingredients: an ordinary Portland cement, fine aggregate, silica fume, superplasticizer and high reactive metakaolin. The mix proportions of the materials used are presented in Table 8.

Table 8: The mix proportions used in preparing the test specimens

Concrete Mix	Cement kg/m³	Coarse aggregate kg/ m³	Fine aggregate kg/ m³	Silica fume kg/ m³	Water kg/m³	metakaolin by wt. of cement%	SO_3 %
RfeSM1	416.1	678	600	-	188.3	5	0.26
SM1	416.1	678	600	-	188.3	5	0.75
RfeSM2	407.34	678	600	-	188.3	7	0.26
SM2	407.34	678	600	-	188.3	7	0.75
RfeSM3	394.2	678	600	-	188.3	10	0.26
SM3	394.2	678	600	-	188.3	10	0.75
RfeHM1	484.5	1050.6	627.3	-	163.2	5	0.26
HM1	484.5	1050.6	627.3	-	163.2	5	0.75
RfeHM2	474.3	1050.6	627.3	-	163.2	7	0.26
HM2	474.3	1050.6	627.3	-	163.2	7	0.75
RfeHM3	459	1050.6	627.3	-	163.2	10	0.26
HM3	459	1050.6	627.3	-	163.2	10	0.75
RfeRM1	721.88	-	1200	200	190	5	0.26
RM1	721.88	-	1200	200	190	5	0.75
RfeRM2	697.5	-	1200	200	190	7	0.26
RM2	697.5	-	1200	200	190	7	0.75
RfeRM3	675	-	1200	200	190	10	0.26
RM3	675	-	1200	200	190	10	0.75

5. Workability of concrete

Slump test was performed according to ASTM C143-00 [16] to adequate the workability of high performance concrete mixes as shown in Table 9, while Slump flow test, V-funnel test and L-Box test were done to check the satisfaction of workability for self-compacted concrete mixes accordance to EFNARC 2005/ SF1[15] as shown in Table 10.

Table 9: Fresh concrete test results for high performance concrete

Concrete Mix	Slump (mm)
RefHM1	100
HM1	99
RefHM2	98
HM2	94
RefHM3	95
HM3	90

Table 10: Fresh concrete test results for self-compacted concrete

Concrete Mix	Slump test		V-funnel test		L- Box test		
	Slump flow (mm)	T500 (sec)	TV_{min} (sec)	$TV_{5 min}$ (sec)	Δ H (H2/H1)	T20 cm (sec)	T40 cm (sec)
RefSM1	635	2.75	7.43	9.79	0.93	1.63	4.67
SM1	628	3.01	11.2	13.8	0.9	2.35	6.88
Ref SM2	623	2.81	8.23	11.13	0.89	1.18	3.97
SM2	615	3.15	12.64	15.8	0.86	4	4.4
Ref SM3	612	2.89	8.94	14.6	0.87	3.24	6.17
SM3	605	3.27	13.8	18.93	0.83	4.7	10.8

6. Hardened concrete tests.

6.1 Compressive strength test

The compressive strength test was made according to B.S.1881: part 116 [17] using the average of two cubes with dimensions of (100×100×100) mm for each test.

6.2 Flexural strength test

This test was carried out using prism specimens of dimensions (100×100×400) mm in accordance with ASTM C293, 2006 [18] on average of two prism for each test.

6.3 Splitting tensile strength test

The splitting tensile strength test was carried out in accordance with the ASTM C496-/C496M-11(19). Cylindrical concrete specimens with dimensions (100×200) mm were used to attain this test.

7. Results and discussions

The first mechanical property that's investigated in this study was the compressive strength. The output of the adopted mixes (SCC, HPC and RPC) have showed that the percentage of metakaolin had a different level of positive effect on the compressive strength for both cases including and excluding of internal sulphate attack as shown in Tables (11,12 and 13) and Figures (1, 2 and 3). This effect reached at 28 days of curing to (11.86, 10.22 and 4.75)% in case of excluding sulphate attack and to (13.82, 11.47and 6.53)% in the other case for SCC, HPC and RPC respectively. It can be concluded that the effect of metakaolin in both SCC and HPC mixes is more influence than in RPC which caused by the existing of silica fume as a constitutive material in RPC since it increases the value of the compressive strength with high percent compared to the increase caused by the metakaolin in the same mix as shown in Tables (14 and 15) and Figures (4 and 5).

The value of compressive strength for all the considered concrete mixes between the including and excluding of internal sulphate attack has showed a different percentage of reduction in its magnitude with respect to curing age. The maximum reduction in the compressive strength was gained in RPC and SCC at age of 7 days to be (6.9 and 6.5)% respectively, while it was 4.75% for HPC. This belongs to the specialty of the RPC and SCC mix proportion, which characterized by a large percentage of fine aggregate as compared to HPC mix. This reduction in the compressive strength varies with curing age, the largest amount of this reduction was concentrated tile (28) days of curing to lie between (45-55)% while the difference between the including and excluding of internal sulphate attack from (90- 120) days varies between (12- 16)% due to the fact that the influence of the additive material (metakaolin in all mixes) started to be significant at later ages of curing and due to the fact that the influence of the of internal sulphate attack is concentrated at earlier ages since it has a negative effect on the activity of cement hydration .

Regarding the splitting and flexural strength, there was a similarity in the behavior that's caused by adding metakaolin. The flexural strength increased by (15.38, 9.42 and 5,84)% at age of 28 days of curing when the sulphate attack is excluded, while it was (14.02, 10.66 and 4.28)% in case of sulphate attack included for SCC,HPC and RPC respectively as shown in Tables (16, 17 and 18). There was also an increase in the splitting tensile strength for both including and excluding of sulphate attack reached to (13.03, 12.95and 9.17)% and (16.88, 10.33 and 6.74)% respectively for the adopting concrete types SCC, HPC and RPC as shown in Tables (19, 20 and 21).

Table 11: Compressive strength for self-compacted concrete

Sample	Compressive Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefSM1	28.8	35.4	43.3	52.2	63.9
SM1	26.93	33.56	41.44	50.23	61.60
RefSM2	29.3	36.6	44.3	53.4	65.3
SM2	27.63	34.97	42.66	51.67	63.29
RefSM3	32.3	39.6	48	56.9	69.2
SM3	30.81	38.20	46.59	55.41	67.48

Table 12: Compressive strength for high performance concrete

Sample	Compressive Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
Ref HM1	40.3	50.9	62.7	74.8	85.3
HM1	38.39	48.92	60.53	72.42	82.67
RefHM2	42.1	53.2	64.9	76.6	87.3
HM2	40.36	51.43	62.98	74.55	85.05
RefHM3	46.2	56.1	66.8	77.6	88
HM3	44.74	54.53	65.14	75.84	86.31

Table 13: Compressive strength for reactive powder concrete

Sample	Compressive Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefRM1	57.4	82.1	91.5	97.5	98.7
RM1	53.44	78.13	88.03	94.27	95.64
RefRM2	59.4	84.2	93.6	98.5	99.6
RM2	55.92	80.84	90.53	95.73	97.26
RefRM3	60.3	86	95.2	100.2	101.4
RM3	57.41	83.23	92.78	98.18	99.42

Table 14: Effect of adding metakaolin on the compressive strength (sulphate attack excluding)

Curing time (days)	According to Ref SM1		According to RefHM1		According to RefRM1	
	Ref SM2 %	Ref SM3 %	Ref HM2 %	Ref HM3 %	Ref RM2 %	Ref RM3 %
28	3.39	11.86	4.52	10.22	2.56	4.75
60	2.31	9.79	3.51	6.54	2.30	4.04
90	2.30	9.00	2.41	3.74	1.03	2.77
120	2.19	8.29	2.34	3.17	0.91	2.74

Table 15: Effect of adding metakaolin on the compressive strength (sulphate attack including)

Curing time (days)	According to SM1 (5% Metakaolen)		According to HM1 (5% Metakaolen)		According to RM1 (5% Metakaolen)	
	SM2 %	SM3%	HM2%	HM3%	RM2%	RM3%
28	4.21	13.82	5.14	11.47	3.47	6.53
60	2.93	12.41	4.06	7.62	2.84	5.40
90	2.85	10.30	2.94	4.72	1.55	4.15
120	2.74	9.55	2.88	4.41	1.70	3.95

Table 16: Flexural strength for self-compacted concrete

Sample	Flexural Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefSM1	9.7	11.9	14.4	17.3	20.6
SM1	9.08	11.29	13.78	16.67	19.87
RefSM2	10.1	12.4	15.2	18.4	21.9
SM2	9.51	11.83	14.63	17.80	21.21
RefSM3	11.4	13.73	16.4	19.4	22.7
SM3	10.50	12.87	15.40	18.20	21.40

Table 17: Flexural Strength for high performance concrete

Sample	Flexural Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefHM1	13.5	17.1	20.7	24.8	28.8
HM1	12.86	16.44	19.99	24.01	27.91
RefHM2	14.01	17.5	21.6	26.1	30.6
HM2	13.43	16.92	20.97	25.40	29.81
RefHM3	15.4	18.71	22.4	26.6	31.2
HM3	14.92	18.19	21.85	26.00	30.61

Table 18: Flexural Strength for reactive powder concrete

Sample	Flexural Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefRM1	19	27.4	30.3	32.4	32.8
RM1	18.6	26.8	29.8	32	32.4
RefRM2	19.7	28.1	31.3	33.3	33.9
RM2	19.2	27.7	31	32.5	33.4
RefRM3	20.4	29	32.4	34.2	34.8
RM3	19.8	28	31.7	33.9	34.3

Table 19: Splitting strength for self-compacted concrete

Sample	Splitting Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefSM1	3.4	4.2	5.15	6.21	7.43
SM1	3.18	3.98	4.93	5.98	7.16
RefSM2	3.77	4.7	5.83	7.13	8.53
SM2	3.54	4.32	5.19	6.2	7.37
RefSM3	4.31	5.26	6.33	7.61	9
SM3	3.67	4.5	5.48	6.57	7.81

Table 20: Splitting strength for high performance concrete

Sample	Splitting Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefHM1	4.61	5.71	6.81	7.93	9.1
HM1	4.32	5.25	6.32	7.57	8.85
RefHM2	4.82	5.86	7.1	8.35	9.48
HM2	4.61	5.63	6.82	8.14	9.26
RefHM3	5.21	6.3	7.5	8.73	9.83
HM3	4.9	5.93	7.1	8.42	9.64

Table 21: Splitting strength for reactive powder concrete

Sample	Splitting Strength (MPa)				
	7 days	28 days	60 days	90 days	120 days
RefRM1	6.4	9.2	10.31	10.83	11.1
RM1	6.13	8.72	9.84	10.65	10.8
RefRM2	6.73	9.51	10.62	11.31	11.5
RM2	6.3	9.1	10.41	10.9	11.2
RefRM3	7.1	9.82	10.85	11.53	11.87
RM3	6.7	9.52	10.6	11.34	11.64

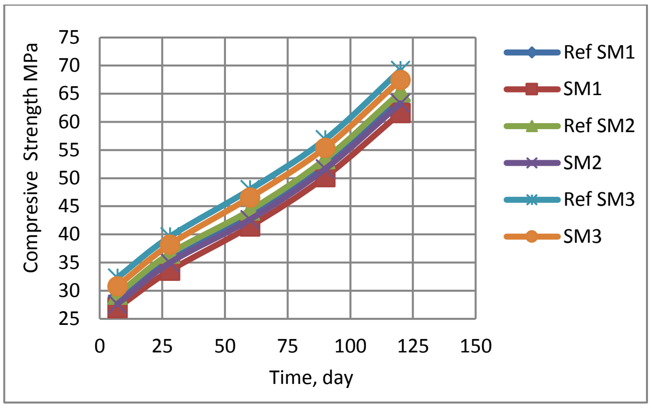

Fig.1: Compressive strength of self-compacted concrete

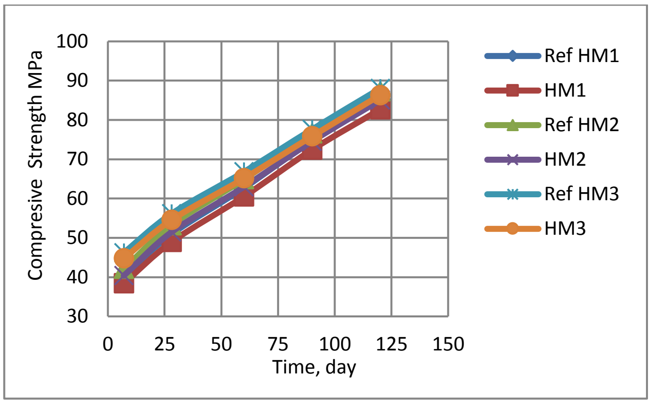

Fig. 2: Compressive strength of high performance concrete

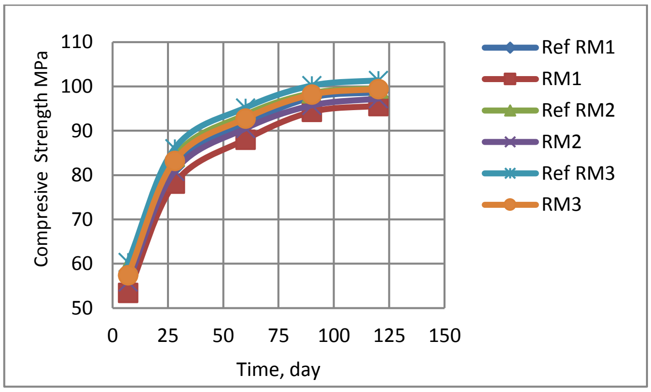

Fig. 3: Compressive strength of reactive powder concrete

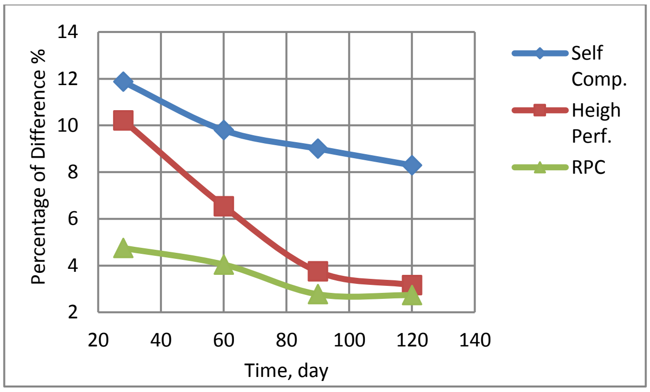

Fig. 4: Effect of adding metakaolin on the compressive strength (sulphate attack excluding)

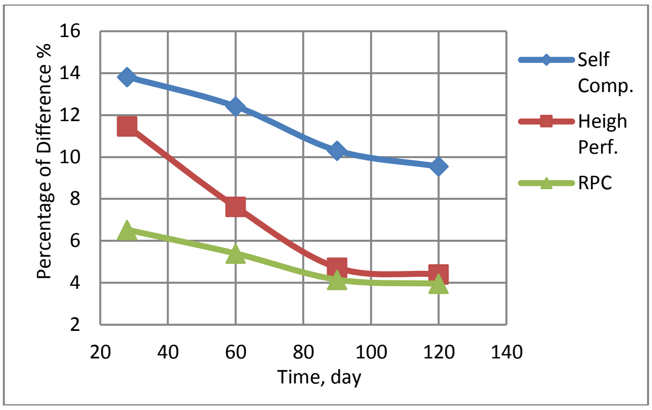

Fig. 5: Effect of adding metakaolin on the compressive strength (sulphate attack including)

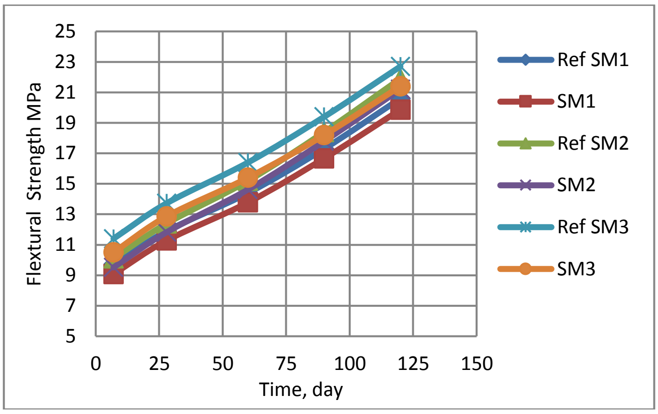

Fig. 6: Flexural strength of self-compacted concrete

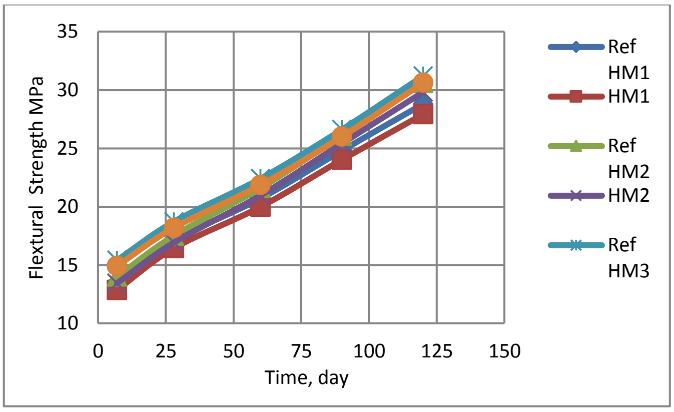

Fig. 7: Flexural strength of high performance concrete

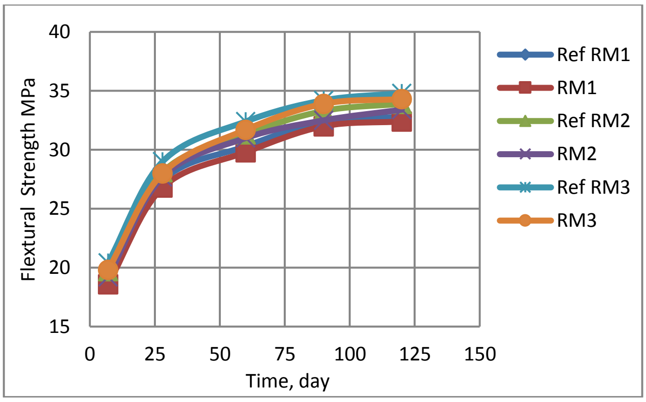

Fig. 8: Flexural strength of reactive powder concrete

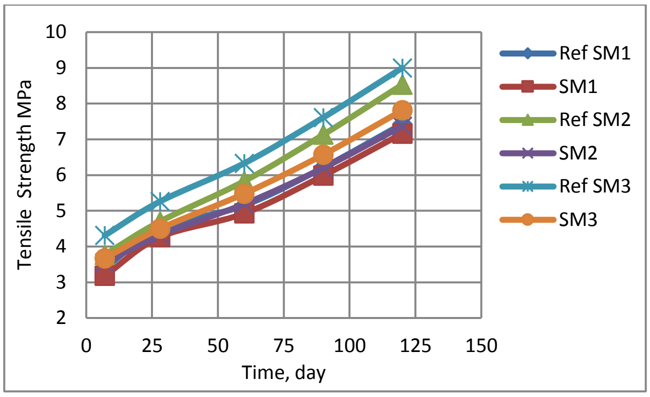

Fig. 9: Splitting tensile strength of self-compacted concrete

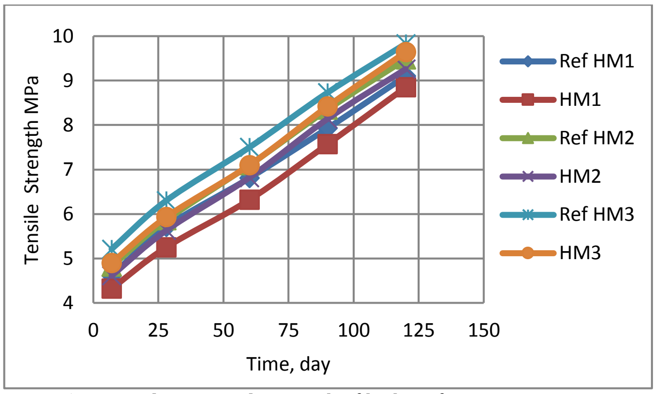

Fig. 10: Splitting tensile strength of high performance concrete

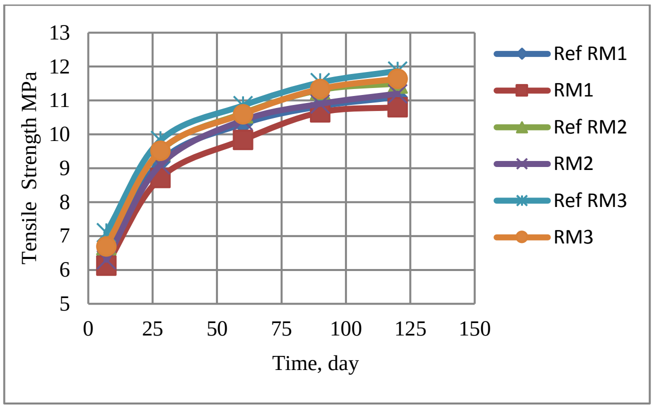

Fig. 11: Splitting tensile strength of reactive powder concrete

8. Conclusion

1. Adding metakaolin as a partial replacement of cement increased the efficiency of all the studied concrete types SCC, HPC and RPC since it cause a significant increase in the hardening mechanical properties (compressive, flexural and splitting tensile strength).
2. The advanced effect of metakaolin on the properties of both SCC and HPC is more efficient than in RPC.
3. Existing of internal sulphate attack reduces the positive effect of metakaolin especially for RPC and SCC since they contain a large amount of fine aggregate than in HPC.
4. The reducing in the studied mechanical properties of all the adopted concrete mixes due to the influence of internal sulphate attack was more significant in the earlier ages of curing.

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