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CORROSION RESISTANCE OF CONCRETE SPECIMENS SUBJECTED TO SULPHATE SOLUTION

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خلاصة : ـ إن مشكلة التآكل الذى يحدث فى الخرسانة أصبحت موجودة بنسبة ملحوظة فى العالم ومنها مصر وبخاصة فى المناطق الساحلية . عُملت هذه الدراسة للمقارنة بين قوة مقاومة الخرسانة المصنوعة من ثلاثة أنواع مختلفة من الأسمنت الموجود فى السوق المحلية (أسمنت بورتلاندى عادى ، أسمنت حديدى والأسمنت المقاوم للكبريتات) . عُملت أربعة خلطات خرسانية من كل نوع من أنواع الأسمنت لتغطى النسب التى تستخدم عادة فى صناعة الخرسانة . أُختبرت قوة مقاومة الخرسانة للضغط والشد على عينات الخرسانة الموضوعه فى المياه الموجود بها أملاح الكبريتات وأخرى فى مياه نقية بعد فترات ٢٨ ، ٦٠ ، ٩٠ ، ١٢٠ يوم من تاريخ الصب . أوضحت النتائج أن أفضل أنواع الأسمنت لمقاومة الكبريتات هو الأسمنت الحديدى .

ABSTRACT :

The problem of corrosion has reached major proportions in many parts of the world. This problem has also been encountered in Egypt, especially in the coastal areas.

The present work was undertaken to compare between corrosion resistance of three types of locally produced cements (ordinary portland, blast furnace, and Sulphate resisting cement). Four concrete mixes from each cement were chosen to cover most of the practical mixes which are currently used in many structures in Egypt.

Compressive strength and splitting tensile strength were evaluated after 28, 60,90 and 120 days for specimens attacked by sulpate as well as for similar control specimens cured by fresh water to be as comparison levels. The variation of strengths gives an idea about the influence of sulphate on concrete specimens.

As a result of this research, some useful conclusions and practical recommendations have been reached for concrete protection against corrosion.

1. INTRODUCTION :

It is well known that most damages of reinforced concrete structures are due to the gradual growth of corrosion of concrete elements by sulphate attack.

Calcium, sodium, and magnesium sulphates usually exist in soils with concentrations up to 5% (50 gm/l.). Unprotected concrete foundation elements such as deep piles, isolated footings and raft foundations placed in the ground at depths varying mostly from 1 to 6 ms, are highly susceptible to deterioration and corrosion by sulphate attack.

Indeed, in the last few years, better understanding and reliable knowledge concerning corrosion criteria of concrete was strongly needed for the economical and safety considerations. So, the corrosion of concrete structures has been engaging the activities of workers all over the world.(1)(2)(8)(9)

The aim of this paper is to compare corrosion resistance of three types of locally produced cements (ordinary portland cement [OPC], blast furnace slag cement [BFC], and sulphate resisting cement [SRC], and also to provide more knowledge for both designers and site engineers about the extent to which these cements may stand against sulphate corrosion.

2. EXPERIMENTAL PROGRAM :

Three types of cement were used [OPC], [BFC], and [SRC]. Four concrete mixes were prepared from each type of cement using two cement contents (250 and 450 kg/m^3) and two slump values were chosen for each cement content (80 mm and 10 mm). Table (1) summarizes detailed values for the weights, volumes, and mix proportions of concrete constituents used in this investigation.

2-1. Preparation of attacking solution :

Magnesium sulphate ($Mg\,SO_4 \cdot 7H_2O$) with purity 99% was chosen to represent the corrosive media which attack the concrete specimens. In order to obtain rapid and correct information about the rate of corrosion, rapid method of corrosion testing should be performed. The rate of corrosion was accelerated by increasing the concentration of attacking sulphate solution. This concentration was chosen to be 80 gm/l (80 000 ppm).

2-2. Preparation of specimens:

Concrete mixes were designed, treated, and controlled under similar conditions. The constituents were mixed in dry state for one minute to ensure the uniformity of the mix. Mixing water was added gradually and the contents were mechanically mixed for a period of two minutes. The slump and compacting factor tests were carried out on all concrete batches.

Vibrating table and hand tamping were used during placing of concrete to ensure full compaction. Specimens were removed from the moulds after 24 hours from casting then cured in water until tested.

All concrete specimens which were planned to be attacked by $Mg\,SO_4$, were taken from curing water after 28 days, then marked, and weighed. For each mix three specimen groups were prepared according to the following programme:

1- For first group, routine tests were carried out to obtain the original strength value after 28 days.
2- For second group, control specimens were cured under water for various age periods (60,90,.and 120 days).
3- The third group, specimens were stored under $Mg\,SO_4$ solution (SO_3 = 80 gm/l) for corresponding age periods (60,90,and 120 days) similar to control group specimens which were cured by fresh water.

2-3. Testing of hardened concrete :

Compression test as well as splitting tensile test were carried out on cube specimens 10X10X10 cm. The splitting tensile strength was computed using the following formula:

$$f_s = \frac{2\,P}{\pi\,L^2}$$

where:

f_s = Splitting tensile strength (kg/cm^2)
P = Max. compressive load (kg)
L = Side length of cube (cm)

3. RESULTS AND DISCUSSION :

The obtained results about the influence of corrosion on the mechanical properties of plain concrete specimens will be analyzed and discussed. Mechanical properties included in this study are compressive strength and splitting tensile strength. Strengths were obtained at various ages for both control specimens stored under water and identical specimens attacked by sulphate solution.

The main results of this experimental work and the overall average reductions in strengths which resulted from the chemical attack of magnesium sulphate on concrete specimens may be summarized in figs (1 to 8) and tables 2 & 3. From the figures and tables the following observations may be obtained:

1) Specimens attacked by sulphate showed lower strength than similar ones cured by fresh water. The percentage reduction in strength due to sulphate attack varied between 1.3% and 36% with average value 21%.
2) The average percentage reductions in compressive strength are 28%, 11% and 14% for[OPC], [BFC] and [SRC] respectively. The corresponding reductions in splitting strength are 27%, 19.5% and 26% respectively. These reductions in strength may be due to the chemical reaction between magnesium sulphate and cement which leads to significant expansion and disintegration of concrete elements.
3) The rate of disintegration is influenced by the C_3A (Tri-calcium aluminate) content of the cement. Cements containing less than 6 percent C_3A exhibit strong resistance. However when the C_3A content exceeds 12 percent the concrete is liable to suffer from attack by sulphates no matter what is the density of the concrete.
4) The rate of attack by sulphate solution is affected by a) the condition of concrete and the possibility of such water to penetrate through it, and b) the chemical composition of the concrete. However dense rich concrete with low Permeability will be much more resistant to infiltration by the sulphate water than lean concrete.
5) The good resistance of blast furnace slag cement may be due to the Fact that 35 % of its constituents are chemically nonreactive materials i.e. the adverse reactive materials are 65% only.

4. Mechanism of sulphate attack :

The mechanism of sulphate attack can be explained as:

1- Sulphates react chemically with calcium and aluminum ions in cement paste to form calcium sulphate (gypsum) and calcium sulphoaluminate hydrate (ettringite) according to the following equations:

$$Ca(OH)_2 + MgSO_4 10H_2O \longrightarrow Ca\ SO_4.2H\ O_2 + Mg(OH)_2 + 8\ H_2O$$

Calcium hydroxide + Magnesium sulphate ⟶ gypsum + Magnesium hydroxide.

$$4\ CaO.\ Al_2O_3.19H_2O + 3(CaSO_4.2H_2O) + 7H_2O \longrightarrow 3CaO.Al_2O_3.3Ca\ SO_4.31H_2O + Ca\ (OH)_2$$

Calcium aluminate hydrate + gypsum ⟶ Ettringite + calcium hydroxide.

2- The formed products have considerably greater volume than the compound they replace. This leads to significant expansion and disintegration of concrete element, e.g. the increase in volume due to gypsum is equivalent to 17.7% of the original volume. While the "ettringite" is accompanied by an increase in volume equivalent to 227 % of the original volume, so, the formation of gypsum and ettringite is the main reason for the detrimental sulphate action.

5. CONCLUSIONS :

The main conclusions of this experimental work may be summarized as follows:

1) The choice of attacking material (magnesium sulphate) with (SO_3) concentration 80 gm/l was very reliable in quick determination of the corrosion rate within few days of sulphate attack.
2) Locally produced ordinary portland cement [OPC] response to corrosion attack of concrete specimens with the same role and efficiency for both two strengths (compressive and splitting tensile). It indicated the maximum percentage reductions in strengths.
3) Blast furnace slag cement [BFC] showed high corrosion resistance especially in compressive strength.
4) Sulphate resisting portland cement [SRC] showed medium role in resisting corrosion attack.
5) The best concrete mix for resisting corrosion was given by the rich concrete mix (cement content= 450 kg/m^3, W/C= 0.37) prepared from [BFC]. This mix was able to resist sulphate for 92 days and lose 1% only of its original compressive strength during the overall age period of attacking process. This appriciate the use of (BFC) over all other types.
6) One more important conclusion is that the effect of the attacking material does not begin before 28 days of curing for all three tested cement types. This can be noticed from all the curves presented in this work (Fig.1 to Fig 6.)

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Table (1) Mix proportions of concrete

Aggregates (Agg)				Cement (C)		Water (W)			Mix proportion								Workability		
Sand (S)		Gravel (G)		Cement Content					by weight					by volume			Slump (mm)	Compacting factor	Consistency
Wt.	L.V.	Wt.	L.V.	Wt.	L.V.	W/C	wt.	L.V.	C : S : G			C : Agg		C : S : G					
kg/m³	m³/m³	kg/m³	m³/m	kg/m³	bags/m³	ratio	kg/m³	lit /m³						bags : m³ : m³					
644	0.383	1288	0.8	250	5	0.65	162.5	162.5	1	2.576	5.152	1	7.73	5	0.383	0.800	80	0.94	wet
665	0.396	1330	0.826	250	5	0.55	137.5	137.5	1	2.66	5.32	1	7.98	5	0.396	0.826	10	0.82	dry
548	0.325	1092	0.679	450	9	0.47	211.5	211.5	1	1.214	2.428	1	3.64	9	0.325	0.679	60	0.95	wet
585	0.348	1170	0.727	450	9	0.37	166.5	166.5	1	1.3	2.6	1	3.90	9	0.348	0.727	10	0.82	dry

* LV = Loose Volume

Table 2: Average values of experimental results of compressive and splitting tensile strengths for concrete specimens prepared from various types of cement (OPC, BFC, SRC)

Cement type	Cement Content kg/m³	W / C	Slump (cm)	Mix Symbol	Water Curing		Water Curing (Control specimens)						Immersed in sulphate (SO_3 = 80 gm/l)					
					28 days		60 days		90 days		120 days		60 days		90 days		120 days	
					f_s	f_c	f_s	f_c	f_s	f_c	f_s	f_c	f_s	f_c	f_s	f_c	f_s	f_c
OPC	250	0.65	8	M1	14.6	220	16	223	22	235	22.5	250	14.7	200	21.4	180	15.5	160
		0.55	1	M2	15.4	230	19	280	27	305	28	328	17.9	260	25.5	280	26.5	275
	450	0.47	8	M3	16.4	317	21.9	345	26.2	390	28	440	20.4	330	24.3	375	24.0	288
		0.37	1	M4	23.2	365	24.9	450	31	470	33	510	24.3	425	30.7	440	28	375
BFC	250	0.65	8	M1	11.4	150	15.7	178	18.7	225	20.1	240	19.3	183	21.0	205	18.5	210
		0.55	1	M2	12.9	155	15.2	215	20	260	22.7	288	20.2	238	21.6	240	20	240
	450	0.47	8	M3	16.7	269	19.5	303	22	325	25	335	24.3	313	24.3	330	22.7	288
		0.37	1	M4	22	323	26	350	26.8	370	29	395	29.2	370	28.6	385	26.8	390
SRC	250	0.65	8	M1	18.4	150	18.9	175	21.4	208	22.5	223	19	193	20.1	200	18.5	205
		0.55	1	M2	23.4	228	25.1	283	26	318	26.5	320	24	275	24.5	285	23	285
	450	0.47	8	M3	26	323	27.9	350	28.2	365	31.7	378	27.5	338	28.2	325	29.9	315
		0.37	1	M4	31	393	31.9	430	32.5	480	36	510	33	426	32.5	407	31.6	403

f_s = Splitting strength (kg/cm²) f_c = Compressive strength (kg/cm²)

Table 3: Comparison between strength reductions for concrete specimens.

Mix proportion	Strength Reduction					
	Compression			Splitting tension		
	OPC	BFC	SRC	OPC	BFC	SRC
M1 (250 , 0.65)	36	13	8	30	8	18
M2 (250 , 0.55)	16	17	11	27	20	23
M3 (450 , 0.47)	35	14	17	24	23	30
M4 (450 , 0.37)	26	1	21	28	27	32
Average	28	11	14	27	19.5	26

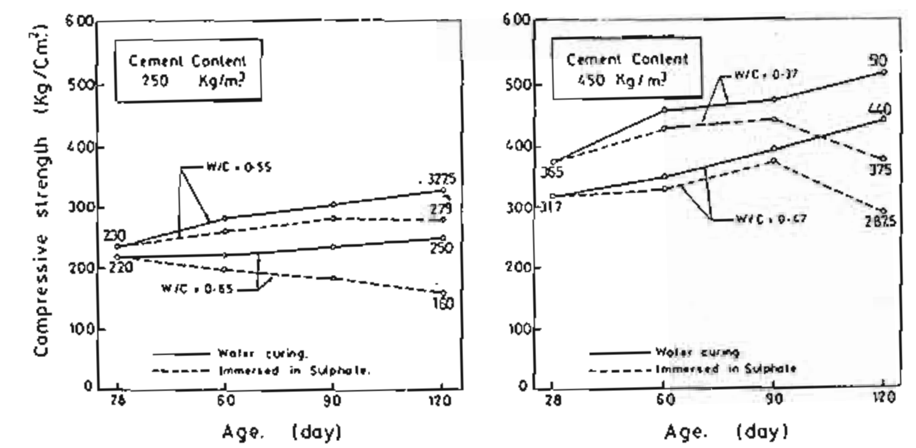

Fig.(1) Influence of magnesium sulphate (SO_4 - 80 gm/l) on compressive strength of concrete cube specimens prepared from ordinary portland cement (OPC).

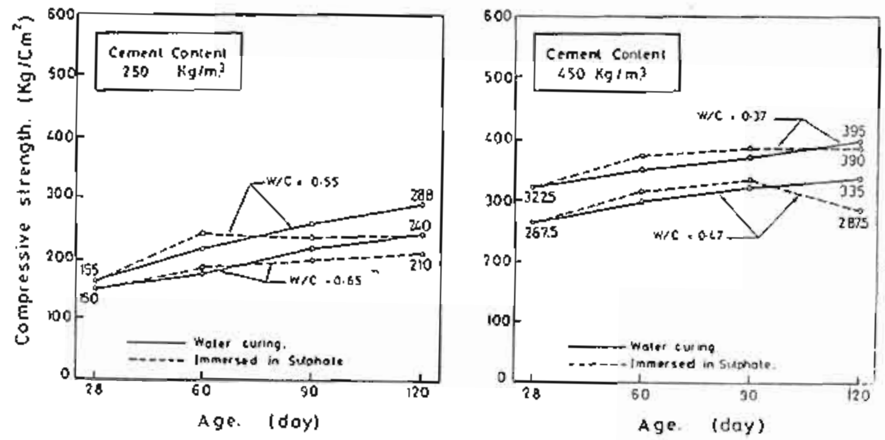

Fig.(2) Influence of magnesium sulphate (SO_4-80 gm/l) on compressive strength of concrete cube specimens prepared from blast furnace slag cement (BFC).

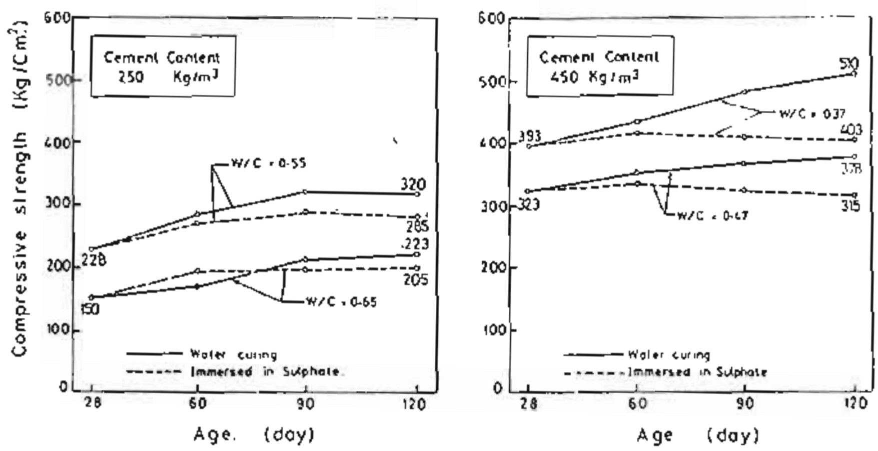

Fig.(3) Influence of magnesium sulphate (SO_4-80 gm/l) on compressive strength of concrete cube specimens prepared from sulphate resisting cement (SRC).

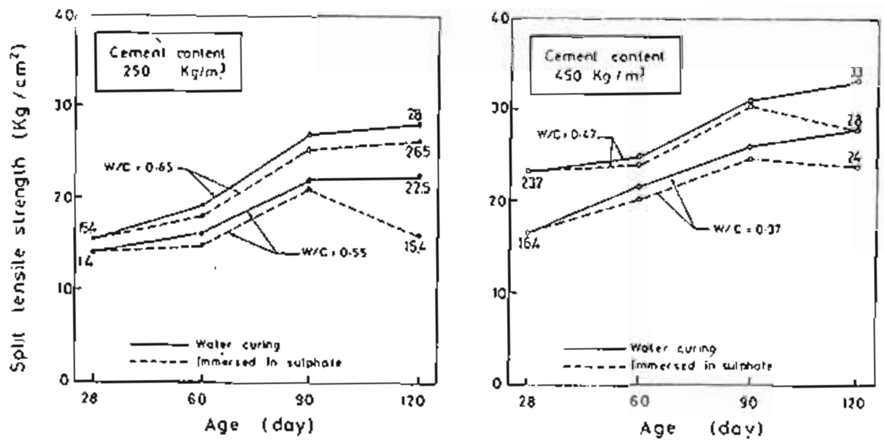

Fig.(4) Influence of magnesium sulphate (SO_4-80 gm/l) on split tensile strength of concrete cube specimens prepared from ordinary portland cement (OPC).

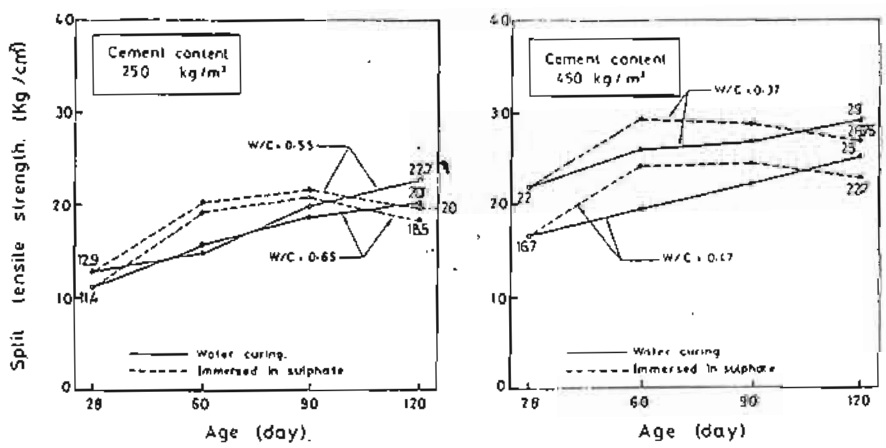

Fig.(5) Influence of magnesium sulphate (SO_4-80 gm/l) on split tensile strength of concrete cube specimens prepared from Blast furnace slag cement (BFC)

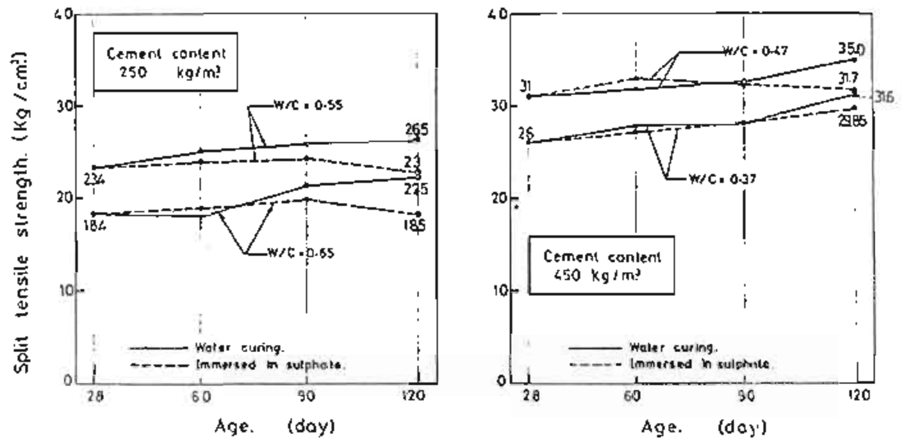

Fig.(6) Influence of magnesium sulphate (SO_4-60 gm/l) on split tensile strength of concrete cube specimens prepared from Sulphate resisting cement (SRC).

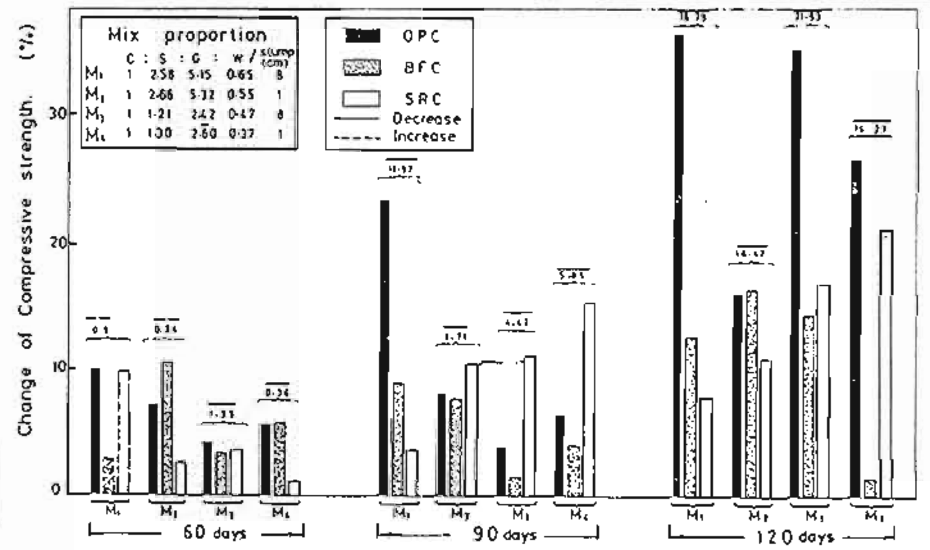

Fig.(7) Relationship between change of compressive strength of concrete specimens exposed to sulphate attack (SO_4-60 gm/l) and type of cement at various ages.

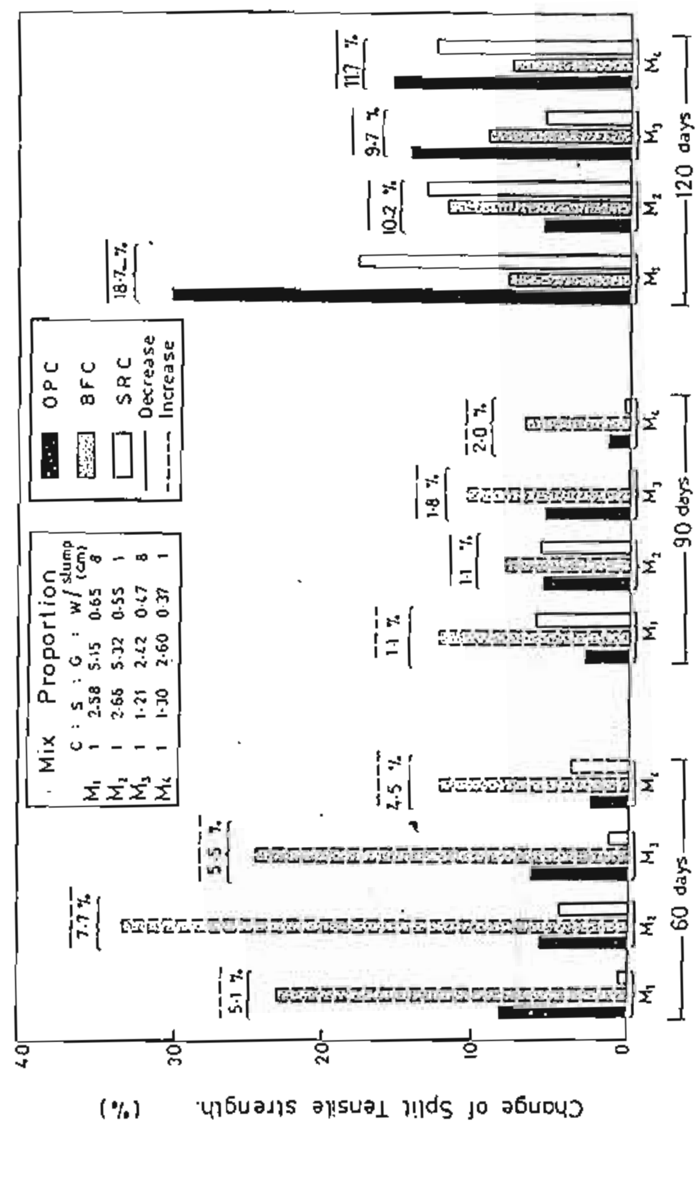

Fig.(6) Relationships between change of split tensile strength of concrete specimens exposed to sulphate attack (SO_4-80 gm/l) and type of cement at various ages.