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EFFECT OF CURING TEMPERATURE AND CONDITIONS ON COMPRESSIVE STRENGTH OF CONCRETE CONTAINING SUPPLEMENTARY POZZOLANIC MATERIALS

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Abstract: Compressive strength is deemed to be one of the most paramount of the mechanical properties of concrete. Lately, there is an increase in trend towards a wider use of some alternative materials added to concrete mixture. Also, there are new methods of curing to obtain the early strength of concrete. Although it is known that high temperatures increase the rate of hydration of cement, the influence of this increase on strength development needs further study's. Different curing temperature and curing methods are usually employed to evaluate the compressive of concrete. This research deals with the study of the effect of curing methods and temperature on compressive strength, density, and absorption of two types of concrete. A 216 concrete cube specimens of two different mixes were prepared at w/c ratio of 0.4 and cement content of 380 kg/m^3 for the reference concrete mix which is designed according to the ACI 211-1 [1]. Second mix was prepared with 4% cement replacement with silica fume by weight. The samples were submerged by water with different curing temperature (20, 40, 60, and 80) C° for 3 hours. After samples cooling, the cubes were divided into three groups (water submerge curing at 20 C°, sealed by polyethylene bags curing, and air curing) until testing ages of (7, 14, 28, 90) days. The results showed that water submerge curing method had the highest compressive strength, density, and lowest absorption, followed by the sealed curing. On the other hand, the lowest compressive strength, density and highest absorption were given by air curing. In addition, the study showed that the best results were obtained by water submerge method and 60 C° curing temperature.

Keywords: *compressive strength, concrete, micro silica, curing method*.

تأثير درجة الحرارة وظروف المعالجة على مقاومة انضغاط الخرسانة الحاوية على مواد بوزولانية

الخلاصة: تعتبر مقاومة انضغاط الخرسانة من أهم الخواص الميكانيكية للخرسانة، وقد ازدادت في الآونة الأخيرة استخدام بعض المواد البديلة للسمنت وذلك بإضافتها إلى الخلطات الخرسانية لغرض الحصول على مقاومة انضغاط مبكرة واستخدام طرق معالجة ودرجات حرارة مختلفة، وبالرغم من معرفة إن الازدياد في درجات الحرارة يزيد من معدل سرعة اكتساب المقاومة فكان لابد من دراسة هذا التأثير. في هذا البحث تم دراسة تأثير طرق المعالجة ودرجات حرارة ماء المعالجة على مقاومة الانضغاط، الكثافة، والامتصاص لنوعين من الخرسانة. حيث تم صب 216 مكعب خرساني لخلطتين مختلفتين، صممت الخلطة المرجعية بالاعتماد على ACI -211بنسبة ماء/ سمنت 0.4 ومحتوى أسمنت قدره 380 كغم /م3 والخلطة الثانية حاوية على غبار السليكا بنسبة استبدال وزنيه مقدارها 4% من السمنت. بعد عملية صب العينات تم معالجتها عن طريق غمرها في الماء وبدرجات حرارة مختلفة (20، 40، 60، و80) م° لمدة ثلاث ساعات وبعد تبريدها تم تقسيمها إلى ثلاثة مجاميع حيث حفظت المجموعة الأولى في الماء بدرجة حرارة 20 م°، بينما تم حفظ المجموعة الثانية بأكياس النايلون وتركت المجموعة الثالثة فيا لهواء بدرجة حرارة المختبر لحين موعد إجراء الفحص بعمر (7،14، 28 و90) يوم. بينت النتائج إن النماذج المغمورة في الماء سجلت أعلى قيم لمقاومة الانضغاط والكثافة وأوطأ قيم للامتصاص.

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تليها النماذج المحفوظة بأكياس البولي أثيلين " بينما سجلت النماذج المتروكة في الهواء أوطأ قيم لمقاومة الانضغاط والكثافة وأعلى قيم للامتصاص، كما أثبتت الدراسة أن أفضل النتائج تم الحصول عليها عن طريق غمر العينات في الماء وبدرجة حرارة 60 درجة مئوية.

1. Introduction

For the purpose of getting a good quality concrete it must be followed by the process of concreting curing in suitable conditions during the early age after hardening of the concrete. Curing can be defining according to the Neville's definition as measures must be taken to provide a suitable moisture which make the concrete remain in certain temperature in order to improve the compressive strength of concrete [2]. The benefits of curing to prevent losses of water, provide condition (additional) for further hydration and prevent or reduce the cracking occur. There are two types of curing, normal curing and Accelerating curing, normal curing includes some of methods, like pounding, sprinkling, using plastic sheets, using curing compounds and other methods. Accelerating curing by (steam, oil, electrical) under high pressure and normal pressure. Concrete strength deprival on the crystals presence in the concrete matrix which resulting from water and cement reaction, in the absence of adequate water, the crystals doesn't grow and increase.

Some of the previous studies [3,4,5,6] have studied the effect of different methods of curing on compressive and density with and without any additive materials. Aliu and Amake [3] studied six methods of curing were used (air curing, water submerged curing, polythene curing, spray curing, moist sand and burlap curing). The specimens were curd until testing ages of (3, 7, 14, 21 and 28) days. The result demonstrated that moist sand curing method produced concrete specimens with the highest compressive strength. On the other hand, air curing showed a reduction in compressive strength after 21 days.

Gokul. etal. [4] carried out un experimental work the investigated the effect of using different curing methods (immersion curing, wet gunny bags curing and accelerated warm water curing compressive strength. The results of the works show that the optimum strengths were achieved by using immersion curing method for both normal and medium strength concrete.

Safiuddin etal. [5] Investigated the effect of three curing regimes (water curing, wrapped curing and dry- air curing) on the properties of concrete containing 10% Microsilica. The overall results of this study suggest that silica fume concrete should be cured by water curing to achieve better hardened properties.

Krishna Rao etal. [6] studies the effect of three methods of curing (conventional wet curing, membrane forming compound curing and accelerated curing) with three types of cement ordinary Portland cement (OPC), Portland Pozzolana cement (PPC) and blended cement (OPC+10% silica fume), through their study concluded that curing compound produces nearly same results as that of conventional wet curing for concrete with OPC. While a marginal decrement is observed in concrete made of PPC and the one in which 10% of OPC is replaced by silica fume.

This research, aims to study the effect of adding 4% silica fume with cement replacement by weight and curing temperature on compressive strength, density and absorption with different curing conditions.

2. Experimental Work

2.1. Materials

All materials used in this study were local materials (cement, sand, and gravel). Silica fume and admixture which controlled by the Central Agency for Standardization and Quality Control were used in the research.

The following is brief summary of those material:

2.1.1. Cement

(Al-Kufa) Iraqi ordinary Portland cement (O.P.C) is used in this study. The compliance of the cement is done according to the Iraqi Standards No.5 (IQS 5) [7]. Tables 1and 2 show chemical and physical properties for ordinary Portland cement.

Table 1: Chemical composition of AL-Kufa Cement (Type (I))

Chemical composition Oxides	%	Specification Iraqi Limits (IQS) No. 5/1984 [7]
Loss on Ignition (L.O.I)	2.06	Not greater than 4%
Silicon Dioxide (SiO_2)	22.00	
Aluminum Oxide ($Al_2 O_3$)	4.62	
Iron Oxide(Fe_2O_3)	3.90	
Calcium Oxide (CaO)	62.41	
Magnesium Oxide (MgO)	2.05	Not greater than 5%
Sulphur Trioxide (SO_3)	1.95	Not greater than 2.8%
Insoluble Residue (I.R)	0.98	Not greater than 1.5%
Tricalcium Aluminate(C_3A)	6.57	-------

Table 2: Physical properties of AL-Kufa Cement

Physical properties		Specification Iraqi Limits (IQS) No. 5/1984 [7]
Specific Surface Area (cm^2/g)	3050	Not less than 2500
Initial setting time (min)	165	Not less than 45
Final setting time (min)	270	Not greater than10 hr.
Comp. Str. 3days (MPa)	29.6	Not less than 15
Comp. Str. 7 days (MPa)	31.2	Not less than 23

2.1.2. Silica Fume

Indian Silica fume with Specific Surface Area (200 m^2/kg) was used as an alternative materials replacement with cement 4% by weight. According ASTM C-240-5 [8]. Physical requirements for silica fume shown in Table 3.

Table 3: Physical requirements for Silica Fume

Properties	Test results	ASTM –C 1240-05 [8] Specification
Specific surface area (m^2/kg)	20065	
Specific density, (kg/m^3)	1792	
Oversize on 45 µmm (%)	1.2	10 max.
Loose bulk density, (kg/$m^{3)}$	658.6	
Accelerated pozzolanic activity (7days)	112	105 min.

2.1.3 Water Mixing and Curing

Tab water is used in this study.

2.1.4 fine Aggregate

Natural sand with F.M (2.8) from AL- Ukhaider region is used conforms to the IQS No. 45 / 1984[9]. Table 4 shows grading of fine aggregate, zone 2.

Table 4: Grading of fine aggregate

Sieve Size(mm)	Passing (%)	specification Limits (IQS 45/1984) [9]			
		ZONE 1	ZONE 2	ZONE 3	ZONE 4
10	100	100	100	100	100
4.75	95.3	90-100	90-100	90-100	95-100
2.36	88.3	60-95	75-100	85-100	95-100
1.18	66.6	30-70	55-90	75-100	90-100
600	43.8	15-34	35-59	60-79	80-100
300	20.9	5-20	8-30	12-40	15-50
150	1.7	0-10	0-10	0-10	0-15

2.1.5 Coarse Aggregate

Crashed gravel with nominal maximum size of (5-20) mm from Shlat region in Maysan government is used conforms to the IQS No. 45 / 1984[9]. Table 5 shows grading of coarse aggregate

Table 5: Grading of coarse aggregate

Sieve size(mm)	Passing (%)	Specification Limits (IQS 45/1984) [9]		
		(5-40) mm	(5-20) mm	(5-14) mm
37.5	100	95-100	100	-
20	96.8	35-70	95-100	100
14	-	-	-	90-100
10	42.3	10-40	30-60	50-85
5	0.9	0-5	0-10	0-10

2.1.6 Superplasticizer

Commune variable admixture in Iraq (water reducing superplasticizer admixture) which is commercially known as SP95 and complies with ASTM C-494 [10] were used. It is compatible with all type of Portland cement and cement replacement materials. Table 6 shows technical properties of the HRWRA (SP95).

Table 6: Technical properties of the HRWRA (SP95)

Properties	Description
Color	Brown
Form state	Liquid
Freezing point	-2 C° approximately
Chloride Content	Nile
Specific gravity	1.17+0.01 at 25 C°
Air entrainment	Typically, less than 2%

2.2 Concrete Mix Design

Two type of mixes of concrete were used in this work, one of these conventional concrete namely 30 MPa with 0.4 w/c, other mix content 4% micro silica (Silica Fume) replacement with cement by weight.

ACI Code 211-1 [1] design method is used in this work designed this mix. The details of concrete proportion are shown in Table 7.

Table 7: Details of concrete mix

Mix	Cement kg/m^3	Water kg/m^3	Sand kg/m^3	Gravel kg/m^3	4% silica fume by wt.	Admixture L/m^3	w/c Ratio
M	380	152	850	1050	-	6.7	0.40
MK	361	152	850	1050	15.2	7.0	0.40

2.3 Casting and Curing

For compressive strength determination at (7,14, 28 and 90) day, 216 concrete cubes were poured in the mould with size (150*150*150) mm, all cubes were cured by water submerge with (20, 40, 60, and 80) C° curing temperature for 3hour, after 24hr the samples divided into three groups according to the curing conditions, group one cured by immersion curing at 20 C°. Second left in the air in the laboratory, last group keep on polyethylene bag.

After the period of curing the specimens were tested. The average of compressive strength at (7,14, 28 and 90) day results, listed in Table 8.

Table 8: Average of compressive strength (MPa) development of mix (M) and (MK) with different curing temperature

Mix	Days	20 C° Air curing	20 C° Sealed by (polyethylene bag)	20 C° Water submerge curing	40 C° Air curing	40 C° Sealed	40 C° Water submerge curing	60 C° Air curing	60 C° Sealed	60 C° Water submerge curing	80 C° Air curing	80 C° Sealed	80 C° Water submerge curing
M	7	23.6	23.1	24	21.6	25.8	27.9	28	30.2	37.2	18.3	20	22.1
	14	22.4	26.8	27.9	26	29.1	30.1	33.2	36.2	42.9	19.4	20.6	22.9
	28	28.2	31.8	38.7	32.6	35.6	40.8	37.6	40.6	47.8	20.1	23.8	26.3
	90	32.1	38.3	42.4	35.2	41	46.3	40	41.5	48.7	21.6	25	29.2
MK	7	28.6	31.9	36.5	29	33.1	37.8	33.6	36.2	38.9	25.1	22.7	28.9
	14	31	33.2	39	32.1	36	41.1	37	41.5	46.3	29	26.8	29.3
	28	33.8	36.2	44.3	35.6	38.2	46.3	40	43.3	48.9	33.2	34.7	35.6
	90	36	38	46.2	40	40.9	49.6	42.9	48.2	55.6	35.5	36.9	37.8

3. Result and Discussions

3.1 Density and Absorption

The average values of the densities and absorption at 28 days are shown in Table 9. The values ranged from (2380–2493) kg/m^3 for mix M, while the densities of mix MK ranged from (2416-2563) kg/m^3. The water submerges curing method at 60 ºC curing temperature produced specimen with the maximum mean density, and lowest mean with dry curing at 40ºC curing temperature.

Table 9: Details of densities and absorption of mix (M) and (MK) with different curing at 28 day

Mix	Properties	20 C° Air curing	20 C° Sealed by (polyethylene bag)	20 C° Water submerge curing	40 C° Air curing	40 C° Sealed (polyethylene bag)	40 C° Water submerge curing	60 C° Air curing	60 C° Sealed (polyethylene bag)	60 C° Water submerge curing	80 C° Air curing	80 C° Sealed (polyethylene bag)	80 C° Water submerge curing
M	Density kg/m^3	2380	2430	2480	2400	2439	2480	2410	2445	2480	2390	2410	2465
	Absorption (%)	0.12	0.1	0.09	0.12	0.1	0.09	0.11	0.09	0.06	0.14	0.1	0.06
MK	Density kg/m^3	2398	2410	2460	2408	2424	2489	2468	2478	2511	2460	2474	2485
	Absorption (%)	0.1	0.08	0.07	0.09	0.07	0.05	0.07	0.05	0.03	0.11	0.07	0.06

Figs. 1, 2, 3, & 4illustrate the relationship between the curing temperature, density and absorption, respectively for different curing temperature, the increase in the average of densities is caused by silica fume, another reason to the increase is related to the progress of hydration with different curing temperature.

This behavior results in more solid products by the time which leads to fill capillary pores.

The averages of absorption for mix MK recorded the lowest values which ranged between (0.03-0.11) % compared with the absorption of mix M (0.06-0.12) %. However, this variable represents a slight change.

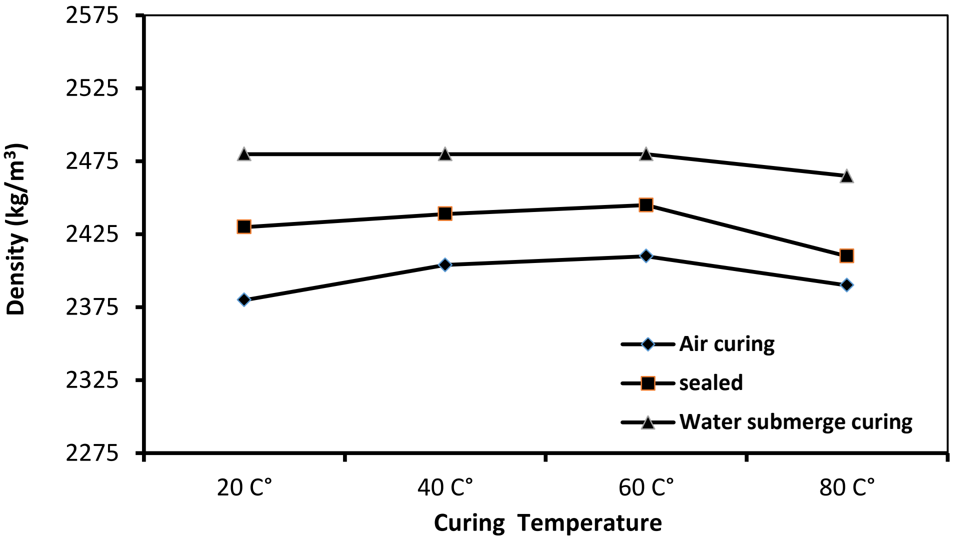

Figure 1: Relation between density and curing temperature with different curing condition for mix M

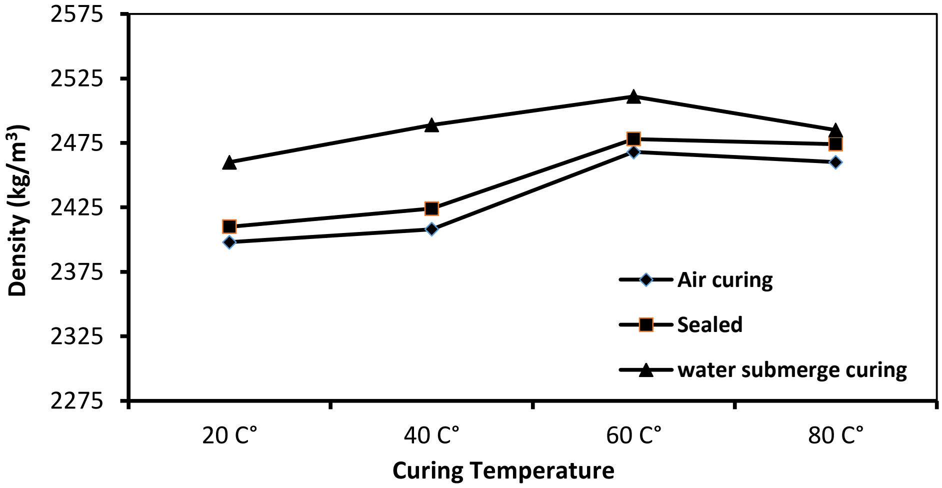

Figure 2: Relation between density and curing temperature with different curing condition for mix MK

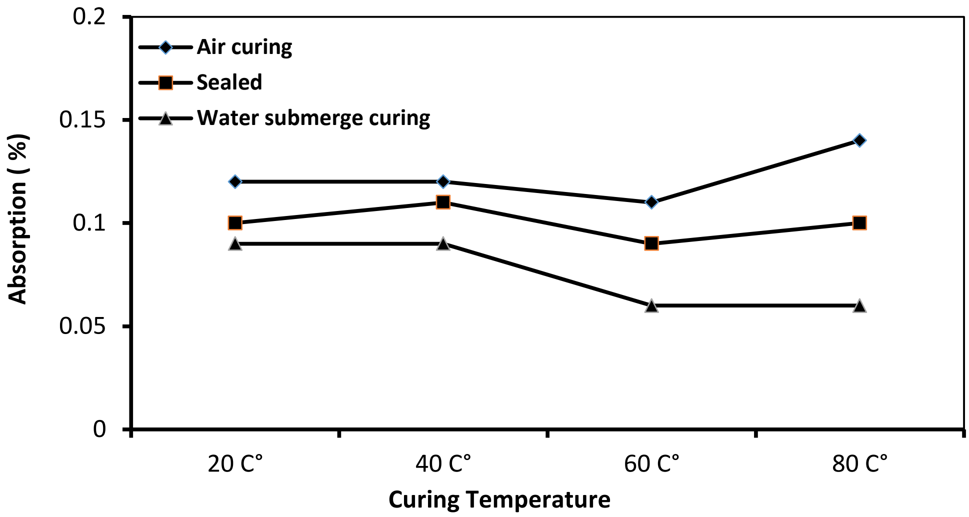

Figure 3: Relation between absorption and curing temperature with different curing condition for mix M

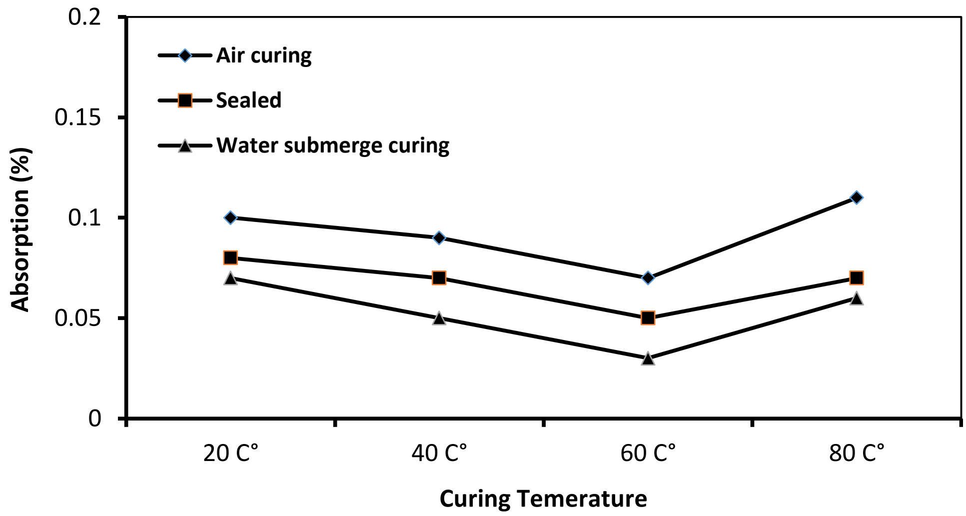

Figure 4: Relation between absorption and curing temperature with different curing condition for mix MK

3.2 Effect of Curing Methods and Temperature

Generally, from figures (5,6,7,8,9,10,11, and12) for different curing methods, the concrete specimens submerged curing in water at 60 C° recorded the highest compressive strength, that makes me agree with Amake [3] and Gokul etal. [4] . Nonetheless, concrete specimens of dry curing 80° C give the lowest compressive strength.

This may be accounted for the large expansion, which leads to microcracking.

3.3 Effect of Silica Fume

A replacement of 4% cement with silica fume by weight improved compressive strength for the MK specimens compared with other ordinary mix (M) for all ages and all curing condition. The replacement has contributed a percentage of 63% to the strength mix design value, as it is shown in figures (5, 6, 7, 8, 9, 10, 11, and 12).

The main reason for this increase, is the ultrafine particles size of silica fume giving The ability to penetrate and filling the pores. On the other hand, silica fume as a pozzolana supplies more regular allocation and more solid products from hydration process.

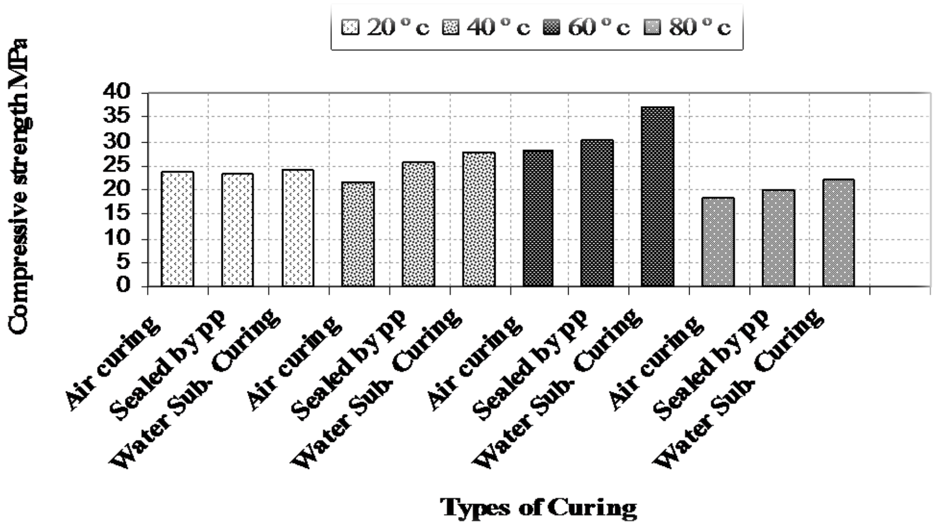

Figure 5: Compressive strength development with different curing condition and temperature at for mix M at 7days

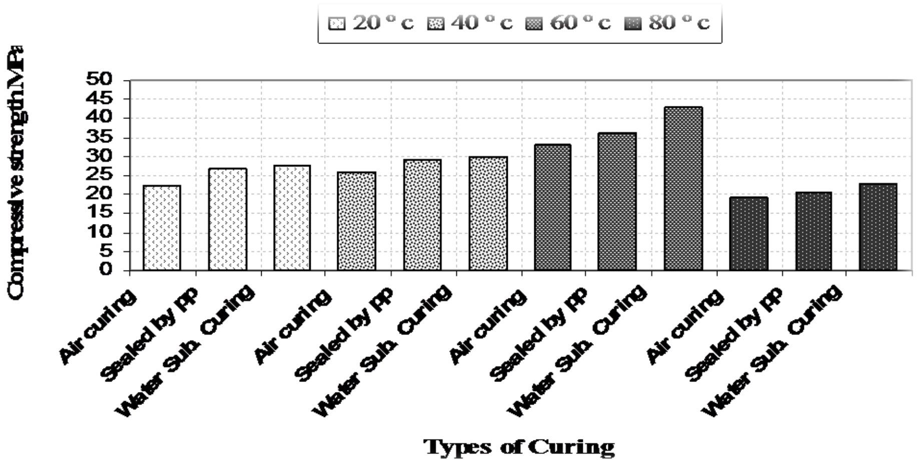

Figure 6: Compressive strength development with different curing condition and temperature at for mix M at 14 days

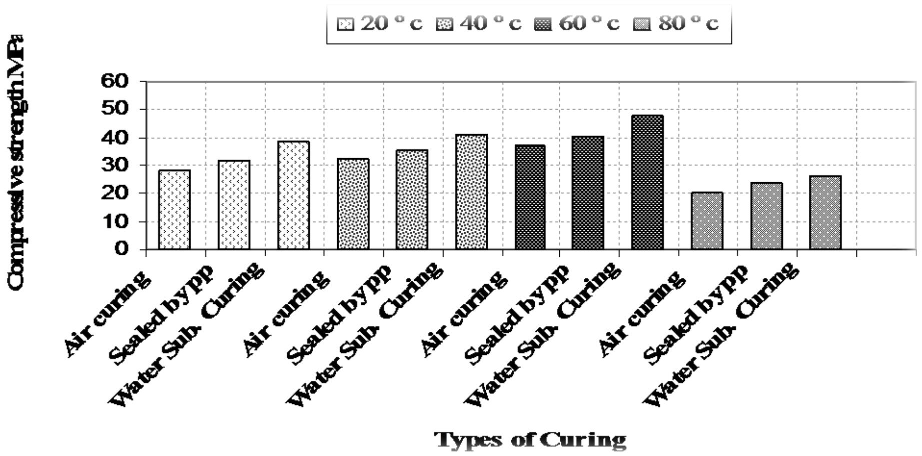

Figure 7: Compressive strength development with different curing condition and temperature at for mix M at 28 days

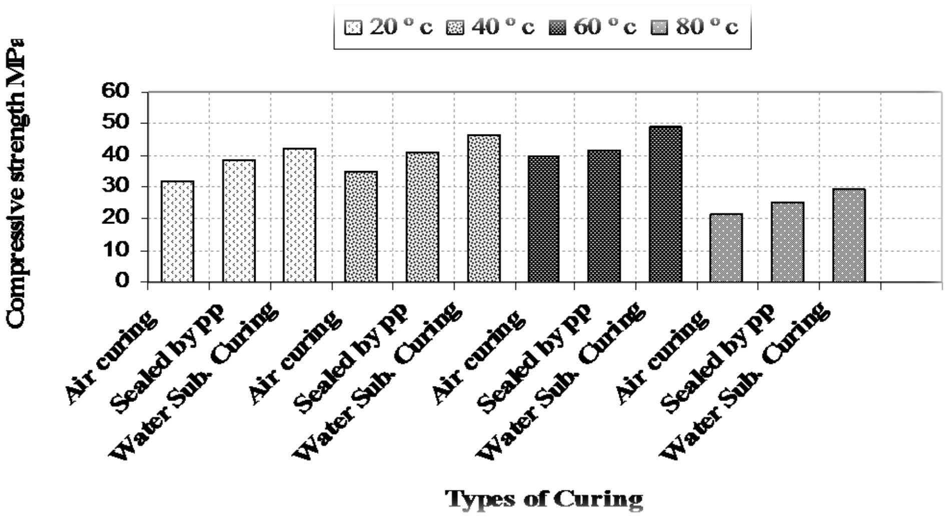

Figure 8: Compressive strength development with different curing condition and temperature at for mix M at 90 days

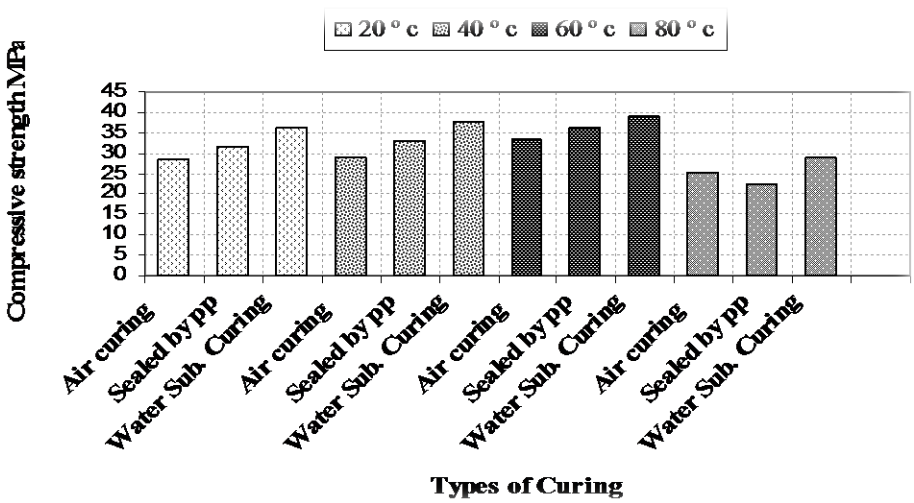

Figure 9: Compressive strength development with different curing condition and temperature at for mix MK at 7 days

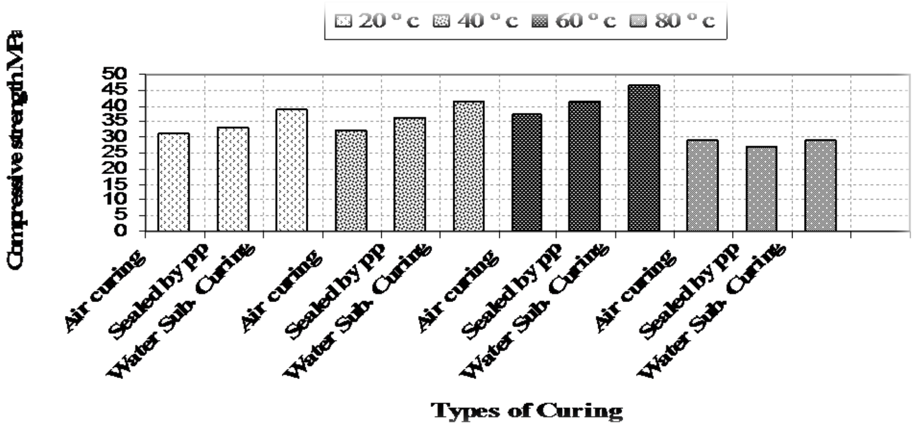

Figure 10: Compressive strength development with different curing condition and temperature at for mix MK at 14 days

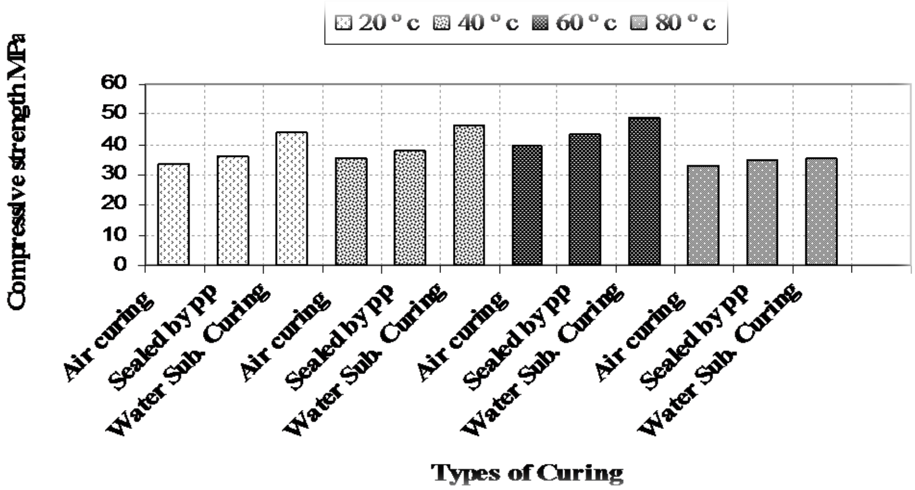

Figure 11: Compressive strength development with different curing condition and temperature at for mix MK at 28 days

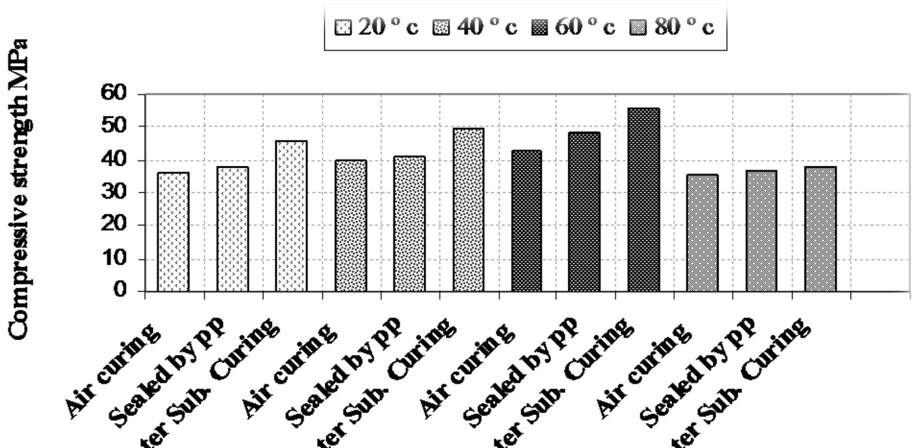

Figure 12: Compressive strength development with different curing condition and temperature at for mix MK at 90 days

4. Conclusions

From this research the following conclusion were obtained:

1. The best results of compressive strength, density, and absorption can be obtained with submerge curing method for concrete
2. The optimum curing water temperature is 60 C°, which gives the best results for strength, density, and absorption.
3. The presence of 4% silica fume improves the properties of concrete significantly. The average of increase is 63% with submerge curing at 60 C°.

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