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RESEARCH ARTICLE

The effects of various curing materials on the compressive strength of concretes produced with / without admixture

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Abstract

The recent earthquakes in Turkey proved the insufficient concrete strength of the buildings in Turkey. Therefore, the effects of various chemical curing materials on concrete compressive strength which are recently widespread and supposed to provide better curing conditions for concrete were investigated experimentally using concrete specimens produced with/without various chemical admixtures in order to investigate how the curing materials affect the compressive strength values of concrete. The concrete test specimens were produced using four different chemical concrete admixtures by subjecting the test specimens to four different curing materials. The results were compared with the concrete compressive strength values of the concrete specimens only cured with water, and the performances of various curing materials on each concrete type were studied in detail. When all the results are taken into consideration, the use of curing materials can be recommended if the determination of the curing water high in quality is not possible.

Keywords

Concrete · curing material · admixture · curing · compressive strength

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1 Introduction

Almost all the lands of Turkey face with significant seismic risks that 98% of its industrial and housing buildings in which nearly 95% of its population lives have been constructed on seismically dangerous regions. Especially the recent earthquakes occurred in Turkey resulted with enormous disasters; for instance, Kocaeli Earthquake in 1999 caused the collapse of 350000 buildings, 20000 fatalities and 45000 injuries (Fig. 1).

The reason for having more than expected damages, fatalities and economic losses in comparison to the magnitudes of the earthquakes was clearly due to significant insufficiencies of the buildings in that city. After completing the investigations executed on these buildings, the concrete strength obtained considerably less than the required value for the reinforced concrete structures in seismic zones was the main reason for the disaster [1–9]. Moreover, it is very tragic that the buildings recently started to collapse under their own weights at the same region [10, 11] (Fig. 2).

Fig. 1. A completely collapsed building in Kocaeli Earthquake [3, 4]

The insufficiencies encountered in concrete strength may be due to various reasons that many studies were conducted on concrete curing period [12–15] and concrete admixtures [16–19, 21] to improve the concrete strength. Any inappropriate curing process is one of the main reasons usually experienced in practice that a proper concrete production may be also concluded with a

Fig. 2. Zumrut Apartment House collapsed in 2005 [9]

lower strength value than the one projected by the codes due to inconvenient curing conditions. Consequently, although a construction having lower concrete strength provides all other requisites, it can not respond against seismic effects during an earthquake and fails. Past to present, various methods and material investigations have been studied in order to improve the curing conditions.

In order to improve the low concrete strengths of incapable constructions in Turkey, the effects of some chemical curing materials on the compressive strength of the concrete specimens produced with/without chemical admixtures were investigated experimentally. Although the use of chemical concrete admixtures does not carry any absolute necessity in terms of concreting, the production of concrete without any admixture more and more decreases with every passing day. Because the use of admixtures becomes almost inevitable both for fresh and hardened concretes in order to improve the concrete characteristics especially in terms of time and strength. In general, the past studies proved that the use of chemical admixtures for concrete production favorably affected the properties of concrete [22, 23].

The objective of this study was to investigate the effects of the curing materials on the compressive strength values of the concretes produced with/without concrete admixtures frequently preferred in concrete production in recent years. It was also thought that the curing materials would cause to have different compressive strength values according to the type of the chemical curing material. Therefore, the appropriateness of using curing materials for the concretes produced with/without admixtures was investigated.

For this purpose, the effects of chemical curing materials on the compressive strength values of concrete were experimentally investigated by applying various chemical curing materials on the concrete specimens prepared with/without chemical admixtures. The results for concrete specimens cured with chemical curing materials were compared with the ones cured only with water and the sort of results obtained for any type of curing material and for any type of concrete mixture were obtained.

2 Experimental Study

The material properties for the concrete mixture (Turkish Code, TS EN 206-1 and TS 802) [24, 25] used in the experimental study are given in the following.

2.1 Materials

2.1.1 Aggregate

The aggregates of 0-4 mm, 4-12 mm and 12-22.4 mm grain sizes used in this study have been widely used in prefabricated and ready-mixed concrete sectors in Turkey for years. The aggregate grade was designed as appropriate to the Turkish Standards (Turkish Code, TS 130 and TS 707) [26, 27], i.e. existing between the curves of A32 and C32 and closer to the curve of B32. The properties of these aggregates are given in Table 1 and Fig. 3.

Tab. 1. Experimental results for aggregates

	0-4 mm	4-11.2 mm	11.2-22.4 mm
Maximum Grain Size	4	11.2	22.4
Specific Weight	2.67	2.69	2.70
Water Absorption Ratio (%)	1.38	1.06	0.74
Loose Dry Unit Weight (kg/dm^3)	1710	1690	1450
Compacted Dry Unit Weight (kg/dm^3)	1810	1830	1570
Washable Fine Material Ratio (%)	1,65	3.67	0.65

2.1.2 Cement

The concrete mixtures were prepared using CEM-II/A-M (P-L) 42.5 R type of manufactured appropriate to Turkish Standards (Turkish Code TS EN 196-1 and TS EN 196-2) [28, 29]. The physical and chemical characteristics of this type of cement are given in Table 2.

2.1.3 Water

The mixing water used for the production of concrete test specimens was potable water that is in accordance with the standards (Turkish Code TS EN 1008) [30].

Analysis results of the water used in test mixtures are given in Table 3.

2.1.4 Admixtures

Four different chemical admixtures and their various combinations were used for the production of concrete specimens (Turkish Code TS EN 934-2) [31]. The admixtures can be listed as in the following;

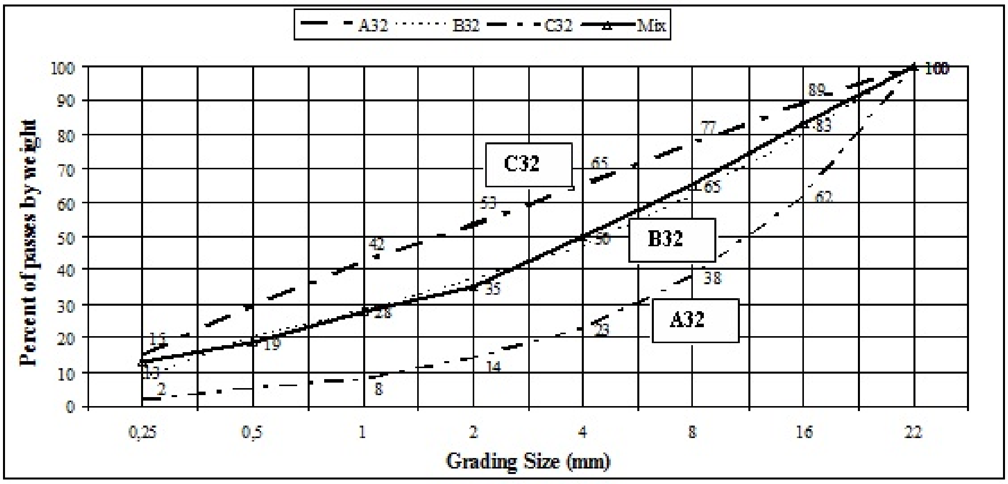

Fig. 3. Grain size distribution curve of aggregates

2.1.4.1 Cold weather concreting admixture This type of concrete admixtures are used to provide concreting under cold weather conditions especially when the conditions of sudden temperature decreases, the touch of frost throughout the day and the frost action throughout the night are expected. They are added to the concrete mixture by adding them into the mixture water or mixing them directly with the just-made fresh concrete having low slump.

Tab. 2. Characteristics of cement

Physical Characteristics	
Specific gravity (gr/cm^3)	3.06
Volume constancy (mm)	2
Liter weight (gr/lt)	1000
Setting period	
Initial setting (hour:minute)	02:30
Final setting (hour:minute)	03:30
Compressive Strength (N/mm^2)	
2 days	24.3
28 days	43.9
Chemical Characteristics	(%)
CaO	1.40
SO3	3.04
Cl^-	0.0032
Tras	10.23
Limestone	5.57
Ignition Loss	3.47

2.1.4.2 Set retarding concrete admixture Concrete admixtures retarding concrete setting by acting on the hydration between water and cement are used to perform easy concreting under humid and windy warm climatic conditions.

Tab. 3. Analysis results of the water used in test mixtures

Properties	**Water Specimen**	**Required Value**
Liquid and Solid Oils	None	None
Detergents	None	None
Color	No	No
Suspended solid material	None	Max. 4 ml
Smell	No	No
Acids (pH)	7.92	≥ 4.0
Organic Material	None	None
Cl^- mg/L	95.75	Maks. 500 Max. 500
SO_4^{-2} mg/L	211.15	Maks.2000 Max. 2000
Total alkali in terms of Na_2O equivalent Na_2O + 0.658 K_2O mg/L	202.51	Max. 1500

2.1.4.3 Waterproofing admixture This concrete admixture provides high level of water impermeability (against water jet or capillary water) in concrete, decreases the water content of the concrete mixture and increases the freezing-thawing resistance of concrete.

2.1.4.4 High performance superplasticizer This admixture is generally used for high strength concrete production to provide fluent, workable high strength concrete by decreasing water/cement ratio without making any reduction in cement content or giving any concession from strength.

2.1.5 Chemical curing materials

2.1.5.1 Paraffin Emulsion Based Curing Material Paraffin emulsion based curing material obtained by dissolving paraffin inside water using an appropriate emulgator has a widespread use in Turkey for reinforced concrete slabs, highways, screed concretes, industrial bases, terraces, slope walls, pre-stressed beams and piles in hot climates. The application of the curing material on the horizontal surfaces should be performed after the disappearance of the transpiration water from the surface of concrete and completing all required leveling processes (depending on temperature, the waiting period should be about 0.5 – 2 hours).

2.1.5.2 Hydrocarbon Resin Based Curing Material Hydrocarbon resin based curing material is formed by thermoplastic resins that can dissolve with appropriate solvents. The evaporation of solvent causes to have a weak and brittle film layer disappearing from the surface under mechanical effects and UV light. The application of the curing material on the horizontal surfaces should be performed after the disappearance of the transpiration water from the surface and completing all required leveling processes (depending on temperature, the waiting period should be about 0.5–2 hours).

2.1.5.3 Acrylic Dispersion Based Curing Material The use of acrylic dispersion based curing material depends on the formation of an acrylic film layer on the concrete surface as a result of the evaporation of water in the compound. Since this curing material is a water-based material, its ideal use will be at indoor areas. The application of the curing material on the horizontal surfaces should be performed after the disappearance of the transpiration water from the surface and completing all required leveling processes (depending on temperature, the waiting period should be about 0.5–2 hours).

2.1.5.4 Acrylic Resins Acrylic resins are applied after dissolving in appropriate solvents and a strong film layer is formed by the help of solvent evaporation. They are mostly used for the construction of industrial bases, terraces, slope walls, screed concretes, concreting in hot climates, irrigation channels etc. The application of the curing material on the horizontal surfaces should be performed after the disappearance of the transpiration water from the surface and completing all required leveling processes (depending on temperature, the waiting period should be about 0.5–2 hours).

2.2 Experimental Method

In total, five different series of concrete mixtures (one without any admixture, four with four different concrete admixtures) were calculated, and the concrete specimens were encoded as in Table 4 according to the admixture usage and the applied curing materials. 270 cubic specimens were produced for 9 different curing applications that there were produced six cubic test specimens (three for 7-day, three for 28-day compression tests) for each curing method and each concrete mixture ($6 \times 5 \times 9 = 270$ specimens). The curing process on concrete specimens was carried out in five different ways, one in water and the other four by using four different chemical curing materials based on paraffin emulsion, hydrocarbon resin, acrylic dispersion and acrylic resin. Each curing material was applied on concrete specimens in two ways.

For the first curing application, all the surfaces of the specimens were covered with chemical curing material. At first, the transpiration water of concrete disappeared in 1.5 hours after concreting and then the curing material was applied to the top surface of the specimen. The vertical surfaces and the bottom surface of the specimen were cured with the chemical curing material one day after the removal of the concrete specimen from the mold (Fig. 4).

In the second application, after the disappearance of transpiration water from the concrete surface occurred, only the top surface of the concrete was subjected to curing material, and concrete was placed inside water after one day. Then four different chemical curing materials were applied separately to each concrete mixture in two different ways. In total, nine different curing applications were performed by curing the specimens in water and in chemical curing materials in two ways.

All the test specimens were cured at $20 \pm 2\ ^{o}$C until the experiment day was reached. The concrete specimens can be classified according to the admixtures used for their preparations as in the following;

1: No admixture
2: Cold weather concreting admixture
3: Set retarding concrete admixture
4: Waterproofing admixture
5: High performance superplasticizer

and the curing materials are listed in the following according to the chemicals they involve;

A: Water
B: Paraffin emulsion based
C: Hydrocarbon resin based
D: Acrylic dispersion based
E: Acrylic resin

2.2.1 Compressive Strength Testing Method

A mono-block testing machine (Fig. 5) appropriate to the Turkish Standards (TSE 12390-4) [32] was used to test the cubic and cylindrical concrete specimens. Some of the properties of the aforementioned compression machine can be listed as in the following;

Maximum loading capacity: 1200-5000 kN
Maximum vertical opening: 336 mm
Accuracy and repeatability: ± %1
Maximum piston rising: 60 mm
Dimensions: 690×400×h1450 mm

The loading rate of the tests was taken as 0.7 MPa/s for all the specimens. Since Turkish Standards accepts either cubic or cylindrical specimens to be tested for the determination of compressive strength, 150×150×150 mm cubic specimens were selected for the tests of this study.

The properties of the software program belonging to the testing machine can be briefly summarized as in the following. The

a) Curing material application on a specimen

b) After the application of curing material

Fig. 4. The application of curing material

Tab. 4. The encoding of the concrete specimens (members) according to the admixture usage and the applied curing material

Code of mixture	Water-cement ratio	Admixture					Curing				
		1	2	3	4	5	A	B	C	D	E
1/A	0.60	x					x				
1/B	0.60	x						x			
1/C	0.60	x							x		
1/D	0.60	x								x	
1/E	0.60	x									x
2/A	0.57		x				x				
2/B	0.57		x					x			
2/C	0.57		x						x		
2/D	0.57		x							x	
2/E	0.57		x								x
3/A	0.57			x			x				
3/B	0.57			x				x			
3/C	0.57			x					x		
3/D	0.57			x						x	
3/E	0.57			x							x
4/A	0.57				x		x				
4/B	0.57				x			x			
4/C	0.57				x				x		
4/D	0.57				x					x	
4/E	0.57				x						x
5/A	0.54					x	x				
5/B	0.54					x		x			
5/C	0.54					x			x		
5/D	0.54					x				x	
5/E	0.54					x					x

a) The testing machine

b) Testing machine before the test

Fig. 5. Testing machine used for the tests

unit for the "Force" parameter can be selected as "kgf" or "kN" from the menu that the recorded strength values are in kN/mm^2 or kgf/mm^2 units.

The software program calculates the failure load and strength automatically and makes the area calculation itself according to the physical dimensions. The graphical scale of the compressive force applied on the specimen automatically changes in proportion to the time spent during the test. The force scale is automatically selected in 50 tonf, 100 tonf and 200 tonf, and the testing velocity was measured in kgf/cm^{2}s during the test.

The results of the tests separately considered for each concrete mixture by taking the curing application in water as the reference are shown in Tables 5 and 6 comparatively. The final results of each mixture were calculated by taking the average of three identical specimens' compressive strength values.

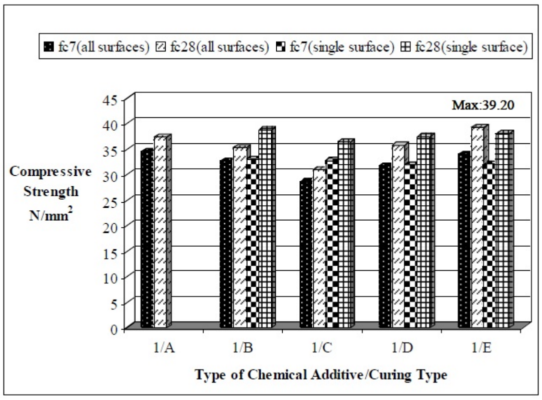

Fig. 6. Graphical comparison of case (1) results among the group

3 Discussions of Results

At the end of the tests, when the concrete compressive strength values of each group having the same mixture ratio but different curing applications were looked over, the specimens cured in water had better compressive strength values than those of the specimens cured with chemical curing materials. E.g. for the concrete specimen produced without any admixture, 7-day and 28-day compressive strength values of the specimens cured

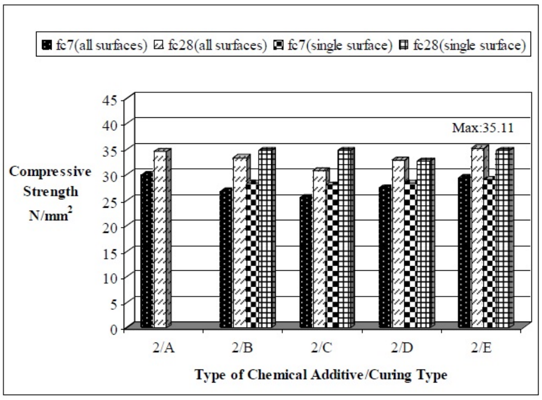

Fig. 7. Graphical comparison of case (2) results among the group

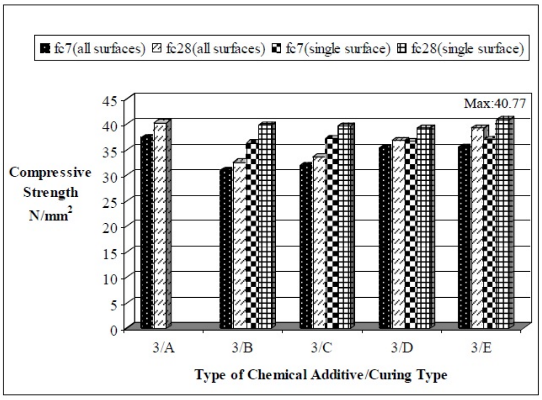

Fig. 8. Graphical comparison of case (3) results among the group

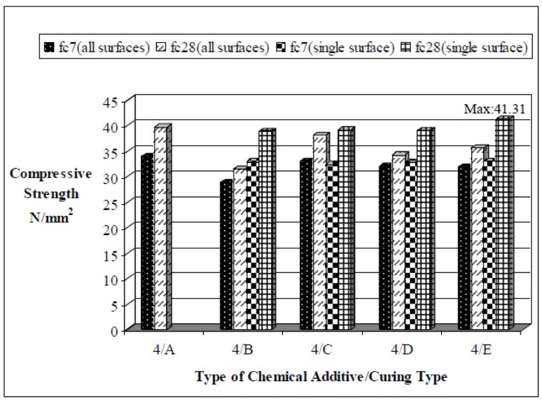

Fig. 9. Graphical comparison of case (4) results among the group

Tab. 5. The comparison of the results for the 1^{st} and 2^{nd} conditions separately by taking the curing application in water as the reference

Explanation	Type of Admixture / Curing Material	Curing Method	% Variation of 7-Day (fck7) Average Compressive Strength	% Variation of 28-Day (fck28) Average Compressive Strength
Taking **1/A** as the reference	1/B	all surfaces	5% decrease	5% decrease
		single surface	4% decrease	4% increase
	1/C	all surfaces	17% decrease	17% decrease
		single surface	5% decrease	3% decrease
	1/D	all surfaces	8% decrease	4% decrease
		single surface	8% decrease	no variation
	1/E	all surfaces	2% decrease	5% increase
		single surface	7% decrease	2% increase
Taking **2/A** as the reference	2/B	all surfaces	11% decrease	4% decrease
		single surface	6% decrease	no variation
	2/C	all surfaces	15% decrease	11% decrease
		single surface	7% decrease	no variation
	2/D	all surfaces	8% decrease	15% decrease
		single surface	5% decrease	6% decrease
	2/E	all surfaces	2% decrease	5% increase
		single surface	3% decrease	no variation
Taking **3/A** as the reference	3/B	all surfaces	17% decrease	19% decrease
		single surface	3% decrease	1% decrease
	3/C	all surfaces	15% decrease	17% decrease
		single surface	no variation	2% decrease
	3/D	all surfaces	5% decrease	9% decrease
		single surface	2% decrease	3% decrease
	3/E	all surfaces	5 % decrease	3% decrease
		single surface	1% decrease	1% increase

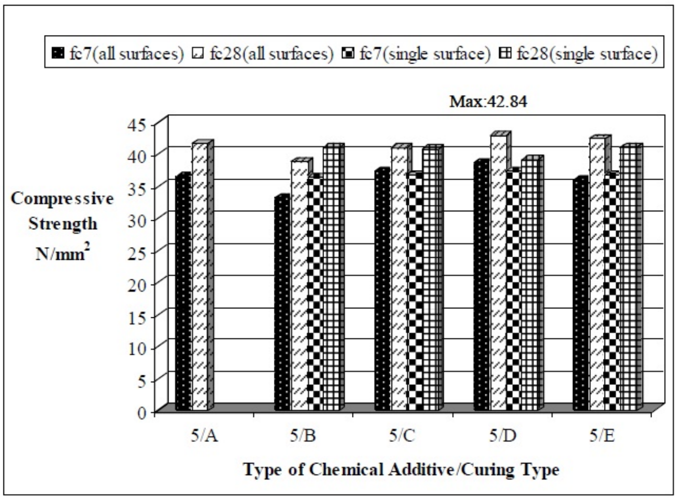

Fig. 10. Graphical comparison of case (5) results among the group

with paraffin based emulsion (1/B) were 5% less than those of the specimens cured in water (Fig. 6).

The concrete specimens having the same concrete mixtures but cured with different chemical curing materials usually displayed the best compressive strength values for the specimens cured with solvent based acrylic resin. For example, the 7-day and 28-day compressive strength values of concrete specimens prepared without any admixture were respectively obtained as 19% and 27% higher for the concrete specimens cured with solvent based acrylic resin (1/E) in comparison to the specimens cured with hydrocarbon resin (1/C) (Fig. 7).

Different concrete mixtures cured with the same chemical curing material presented different results. For instance, the 28-day compressive strength of the specimen prepared with no admixture and cured with solvent based acrylic resin (1/E) had 5% higher strength in comparison to that of the specimen cured with water; on the other hand, the 28-day compressive strength of

Tab. 6. The comparison of the results for the 4^{th} and 5^{th} conditions separately by taking the curing application in water as the reference

Explanation	Type of Admixture / Curing Material	Curing Method	% Variation of 7-Day (fck7) Average Compressive Strength	% Variation of 28-Day (fck28) Average Compressive Strength
Taking **4/A** as the reference	**4/B**	all surfaces	15% decrease	21% decrease
		single surface	3% decrease	2% decrease
	4/C	all surfaces	3% decrease	4% decrease
		single surface	5% decrease	1% decrease
	4/D	all surfaces	6% decrease	14% decrease
		single surface	3% decrease	2% decrease
	4/E	all surfaces	6% decrease	10% decrease
		single surface	3% decrease	4% increase
Taking **5/A** as the reference	**5/B**	all surfaces	9% decrease	7% decrease
		single surface	no variation	2% decrease
	5/C	all surfaces	2% increase	2% decrease
		single surface	1% increase	2% decrease
	5/D	all surfaces	6% increase	3% increase
		single surface	2% increase	6% decrease
	5/E	all surfaces	2% decrease	2% increase
		single surface	1% increase	1% decrease

a) A test specimen cured in water

b) A test specimen cured with curing material

Fig. 11. Deformations on the samples after the tests

the specimen prepared with set retarding concrete admixture and cured with solvent based acrylic resin (3/E) had 3% less strength than that of the specimen cured with water (3/A) (Fig. 8).

Especially the paraffin emulsion based curing material caused to have the minimum compressive strength values for all the concrete mixtures except the concrete mixtures prepared without any admixture and with cold weather concreting admixture. E.g., when the concrete compressive strengths of the specimens prepared with set retarding concrete admixture were examined, the ones cured with paraffin based curing material (3/B) had 17% and 19% compressive strength reductions in comparison to the ones cured with water (3/B) for 7-day and 28-day compressive strength values, respectively. These values are the least values among the group formed with 3/A, 3/B, 3/C, 3/D, and 3/E (Fig. 9-10).

After applying the chemical curing materials on the concrete surface, they cause brittleness at the exterior surface of the concrete. Therefore, sudden cracks occurred on the concrete specimens subjected to chemical curing material, while the specimens cured with water did not face with any. Then, when the specimens cured with chemical curing materials were subjected to compression, they faced with larger deformation and large pieces ruptured from the concrete surfaces (Fig. 11).

The specimens whose only one surface was cured with chemical curing materials and the rest was cured with water had closer compressive strength values to those obtained for the specimens cured only in water.

The specimens subjected to chemical curing materials had plastic shrinkage cracks rarely when compared to the concrete specimens cured in water [33].

4 Conclusions

In conclusion, each chemical curing material tested on concrete specimens produced with/without different chemical admixtures presented different strength characteristics from each other. A curing material that increases the strength of concrete produced with any type of admixture may decrease the strength of concrete produced with another type of admixture; and a curing material that cause to have favorable results for concretes produced without any admixture may present unfavorable results for concretes produced with chemical admixtures. Therefore, the concrete mixture that will be used in a construction should be tested in laboratory before application in order to determine which curing material presents favorable results on which concrete specimens (produced with which chemical admixture) and select the most appropriate one giving the best results. The chemical curing materials should not be thinned with water during their application. If water is added to the curing material, the resultant heterogeneous mixture can not form the required film layer on the surface of concrete and the curing process will not fulfill its performance. Although chemical curing materials are widely used in buildings, their uses especially for the constructions of shallow concrete applications such as highways, airport departure runways, industrial soils, terraces etc. will be more appropriate in terms of easy applicability. When all the test results were taken into consideration, it was observed that the use of chemical curing materials could be preferred if the curing water high in quality was impossible to determine. Finally, in general, it can be said that the concretes produced with chemical admixtures will give appropriate results, if the curing processes of concretes are performed by using convenient curing materials.

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