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Comparative study on the using of PEG and PAM as curing agents for self-curing concrete

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ABSTRACT

There are many factors, which may affect on concrete quality. One of those is concrete curing. Self-curing concrete is the solution. It may produce by using chemical curing agents. The concept of those agents is to reduce the water evaporation from concrete. This research aims to study the effect of chemical curing agents on the behavior of self-curing concrete. Two different chemical curing agents were used to study the main mechanical properties of concrete. The main variables are; the type of curing agent (Polyethylene glycol "PEG400"–Poly Acrylamide "PAM") and its dosages. The results obtained in terms of compressive, tensile and flexure strength values. Test results showed that the self-curing concrete cured by each agent performed better in hardened properties compared to none cured concrete. Also, curing using the both agents together perform better than using each one individually.

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1. Introduction

The curing of concrete is an essential step in the concrete construction. A suitable curing period is essential at early ages to enable the concrete to have strength, to reduce shrinkage, and to develop a structure that will make the concrete sufficiently durable (Schlitter et al., 2010). Curing is the process by which hydraulic cement concrete develops hardened properties over time. Hardening of concrete is a result of the continued hydration of the cement in the presence of sufficient water and heat (ACI.308R–01, 2001). Water is necessary to the hydration reaction of the cement, which led the gray cement powder to convert into the binding cement paste, which gives concrete its strength (ACI.308R–01, 2001; Ambily and Rajamane, 2007). Excessive evaporation of water (internal or external) from fresh concrete led to unsatisfactory properties if it is not avoided. Curing regimes should ensure the availability of adequate amount of water for cement hydration.

Using self-curing "SC" concrete is a good solution to avoid the conventional curing processes (Jensen and Lura, 2006; Schlitter et al., 2010; Jagannadha Kumar et al., 2012; Junaid et al., 2015). It has satisfied characteristics in strength and durability (Dhir et al., 1995; Mather, 2001; Jagannadha Kumar et al., 2012; Kholia et al., 2013; Mousa et al., 2014; Vyawahare and Patil, 2014; Junaid et al., 2015; Bashandy, 2016). Also, SC concrete behaves well at elevated temperatures (Bashandy, 2015). The main idea of self-curing concrete is to cure the concrete from inside to outside. There are two main methods to obtain self-curing concrete (Chella-Gifta et al., 2013). The first is conducted by using porous materials (Lightweight Aggregates, Wood powder) to act as internal reservoirs (Bentur et al., 2001; Kovler et al., 2002; Ambily and Rajamane, 2007). The second is conducted by using chemical curing agents (Super-absorbent Polymers "SAP" and Shrinkage Reducing Admixture "SRA" such as polyethylene-glycol "PEG", polyacrylamide "PAM" and propylene glycol) (El Dieb et al., 2012; Sathanandham et al., 2013). Using PEGs results in self-curing, helps in better hydration, and improves strength (Sathanandham et al., 2013). Also, PEGs reduces early age shrinkage cracks. Adding PEGs to concrete led to forming shells around water particles. Those shells formed on every water particles present in the concrete with thicknesses of about 2nm. Due to the formation of those shells, water is not able to evaporate from concrete. That led to reduces rate

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of evaporation so water is always available at the time when hydration heat is going on. As evaporation does not take place there is no need for curing water (El Dieb, 2007; Sathanandham et al., 2013). PAM increases the strengths of concrete through its functions of absorbing water, filling larger pores, forming polymer films over hydrates, and interacting with hydration process (Rai and Singh, 2005). There are several types of SRAs. Each type of SRA has a different effect on the behavior of the obtained SC concrete (Jensen and Lura, 2006; El Dieb et al., 2012; Sathanandham et al., 2013; Kamal et al., 2016).

2. Research Significance

This research aims to investigate the effect of using two different chemical self-curing agents (PEG400 - PAM) on the hardened properties of concrete in order to obtain self-curing concrete. The main variables are; the type of self-curing agent (PEG400 - PAM) and the dosages of self-curing agents.

The importance of this research is to addressing the behavior of SC concrete for the researchers and engineers to overcome the possible problems due to insufficient curing. Fig. 1 shows the flow chart of the experimental program.

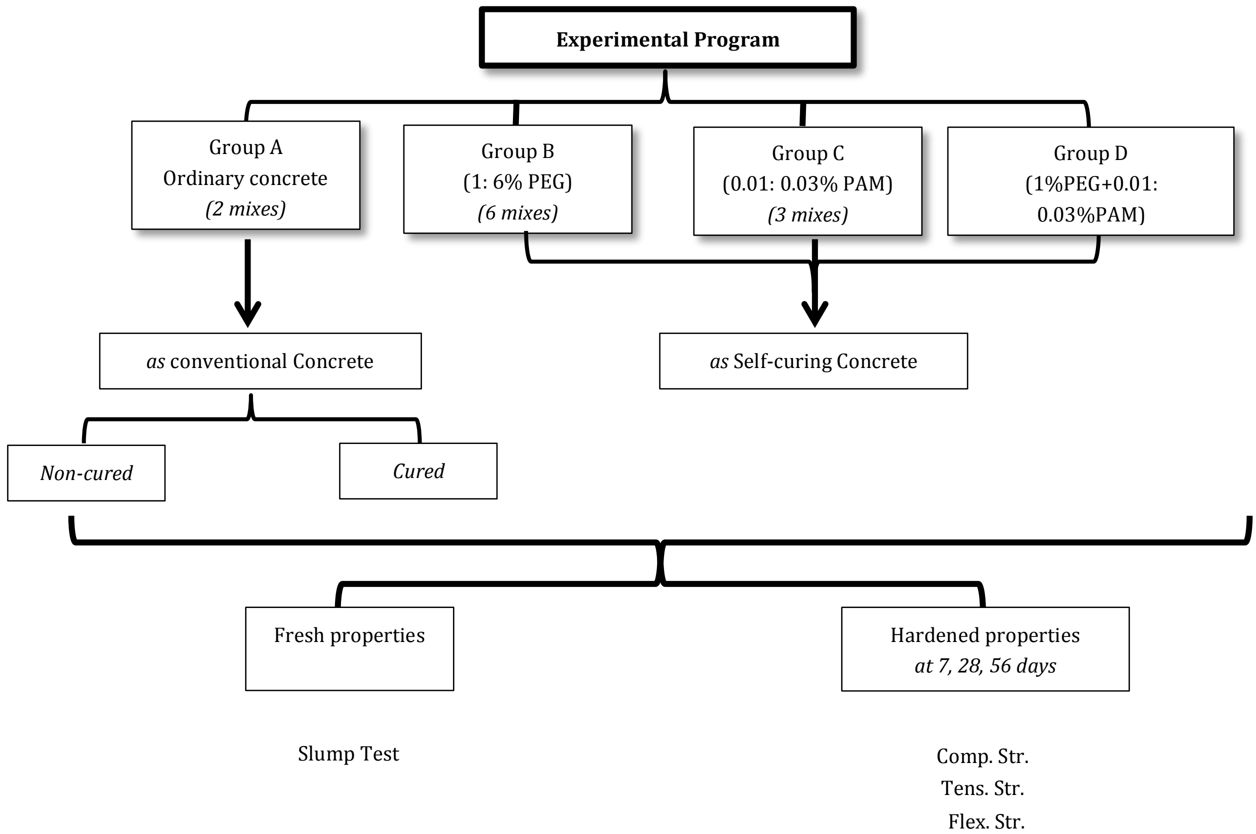

Fig. 1. Flow chart of experimental program.

3. Materials and Test Specimens

All tests in this research were carried out in the concrete research laboratory at Civil Eng. Dep. at Faculty of Engineering, Menoufia University.

The materials used, the design of test specimens and testing procedures are discussed in the following sections.

3.1. Materials

The cement used is ordinary Portland cement CEM I 42.5 N obtained from Lafarge factory. It satisfies the Egyptian Standard Specification (E.S.S. 4756-1/2009). Chemical and physical properties are shown in Table 1.

The fine aggregate used is natural siliceous sand that satisfies the Egyptian standards (E.S.S. 1109/2008). It is clean and nearly free from impurities with a specific gravity of 2.64 and a fineness modulus of 3.05. Its mechanical and physical properties are shown in Table 2.

The coarse aggregates used is crushed dolomite with a maximum nominal size of 10 mm, which satisfies the (E.S.S 1109/2008). Its mechanical and physical properties are shown in Table 3.

Drinkable clean water, fresh and free from impurities was used for mixing and curing satisfying the Egyptian Code of Practice (E.C.P. 203/2007).

A Super plasticizer "SP"as a high range water reducer without retarding effect for concrete is used. It complies with ASTM C-494 type F. The technical data at 25°C is shown in Table 4. Silica fume as a pozzolanic additive is used in powder form satisfied. Chemical and physical properties are shown in Table 5.

The self-curing agents used in this study are two types; Polyethylene glycol 400 "PEG 400"and Polyacrylamide "PAM". PEG 400 is in liquid form as chemical self-curing agent. Sisco Research Laboratories Company, India, manufactures it. The main physical and chemical properties are shown in Table 6. The PAM used is manufactured by Yixing Bluwat Chemicals Co. Ltd., China. The main physical and chemical properties are shown in Table 7.

Table 1. Typical properties of ordinary Portland cement used.

Property		Value
Surface Area	(m^2/kg)	310.0
Setting Time Initial	(minutes)	150.0
Specific Weight	(t/m^3)	3.12
Compressive Strength:		
2 day	(N/mm^2)	20.0
28 day	(N/mm^2)	49.0
Sulfate	SO_3 (%)	2.9
Chloride	CL (%)	0.06
Alkali Eq.	Na_2O (%)	0.50
Tri-Calcium Silicate	C_3S (%)	55.0 : 65.0
Di-Calcium Silicate	C_2S (%)	15.0 to 25.0
Tri-Calcium Aluminate	C_3A (%)	7.0
Tetra-Calcium Aluminoferrite	C_4AF (%)	11.0

Table 2. Typical properties of silica fume used.

Property		Value
Surface Area	(m^2/kg)	15000
Specific Weight	(kg/m^3)	2200
Sulfate	SO_3 (%)	0.30
Silicon Dioxide	SiO_2 (%)	95.0
Aluminum Oxide	AL_2O_3 (%)	0.40
Iron Oxide	Fe_2O_3 (%)	0.60
Calcium Oxide	CaO (%)	0.20
Magnesium Oxide	MgO (%)	0.40

Table 3. Mechanical and physical properties of sand used (as obtained from tests).

Sieve Size	(mm)	4.75	2.00	1.18	0.60	0.25	0.15
Pass	(%)	98.18	81.14	61.61	39.07	13.79	0.66
Fineness Modulus		3.05					
Specific Gravity		2.64					
Volume Weight	(kg/m^3)	1675					
Dust by Weight	(%)	0.01					

Table 4. Main mechanical and physical properties of crushed dolomite used (as obtained from tests).

Sieve Size	(mm)	4.75	2.00	1.18	0.60	0.25	0.15
Pass	(%)	98.18	81.14	61.61	39.07	13.79	0.66
MNS*	(mm)	10					
Specific Gravity		2.58					
Volume Weight	(kg/m^3)	1610					
Absorption Percentage	(%)	1.0					

** MNS = Maximum nominal size*

Table 5. Main properties of Addicrete PVF (as provided by manufacturer).

Property	Value
Base	Naphthalene sulphonate
Appearance	Brown liquid
Density (at 25°C)	1.18 ± 0.01 kg/l
Chloride Content	Nil
Air Entrainment	Nil
Compatibility	All types of Portland cement

Table 6. Main properties of Polyethylene glycol (PEG 400) as curing agent type 1 (as provided by manufacturer).

Property	Value
Average Molecular Weight	380 - 420 g/mol
Viscosity at 20°C	85 - 105 cs
Acidity	0.05% (max)
Wt /ml at 20°C	1.120 - 1.126 gm

Table 7. Main properties of Polyacrylamide (PAM) as curing agent type 2 (as provideD by manufacturer).

Property	Value
Average Molecular Weight	9000000 g/mol
Appearance	White crystalline powder
Specific Gravity	0.75 (50% aq. sol.)
PH Value	5 – 7

3.2. Concrete manufacturing

The start point of choosing the proportions of self-curing concrete mixes was conducted firstly based on previous researches (Yehia, 2010; El Dieb et al., 2012). All components of the concrete mixture of all stages are the same except the type and the dosage of self-curing agent, which considered as the main variable. The mixture proportions are illustrated in Table 8.

The pozzolanic additive (silica fume) used to reduce the concrete permeability then subsequently the concrete mixing water evaporation decreased and retained in the concrete as the self-curing agent does.

Table 8. Proportions of concrete mixes used.

Mixture code	Self-Curing Agent (as % of C)		Cement Content (kg/m³)	Water (kg/m³)	F.A. (kg/m³)	C.A. (kg/m³)	Silica Fume (addition) (as % of C)	S.P. (%)
	PEG	PAM						
NC	--	--	300	150	643	1193	15	0.70
TC	--	--						
SE1	1.0	--						
SE2	2.0	--						
SE3	3.0	--						
SE4	4.0	--						
SE5	5.0	--						
SE6	6.0	--						
SA1	--	0.01						
SA2	--	0.02						
SA3	--	0.03						
SEA1	1.0	0.01						
SEA2	1.0	0.02						
SEA3	1.0	0.03						

3.3. Concrete samples

The conducted experimental program divided to four groups as shown in Tables 8 and 9. The first group performed to study the hardened concrete properties for conventionally cured concrete compared to non-cured concrete. The second group was performed to study the effect of using PEG400 only as the self-curing agent by six varied dosages from 1.0 up to 6.0 % of cement weight to obtain SC concrete. The third group was performed to study the effect of using three different dosages from PAM only as 0.01 to 0.03% of cement weight to obtain SC concrete too. The fourth group was performed to study the effect of using a mix of PEG400 and PAM as a self-curing agent by three different dosages (1.0%PEG + 0.01: 0.03% PAM). Table 9 shows the mix code identification for each group, slump values, and hardened concrete properties.

For all groups, fresh properties obtained in term of slump value The standard cone of dimensions 100mm upper diameter, 200 mm bottom diameter and 300 mm height was used according to the Egyptian Code of Practice (E.C.P. 203/2007). The main mechanical properties obtained in terms of compressive, tensile and flexure strengths according to E.C.P. 203/2007. The specimens are cubes (10×10×10 cm) to obtained compressive strength, cylinder (10cm diameter, 20 cm height) to obtained indirect tensile strength, and prism (10×10×50cm) to obtained flexural strength. A compressive strength testing machine of 2000 kN capacity was used to obtain compressive strength, indirect tensile strength and bond strength. A flexure-testing machine of 100 kN capacity was used to obtain flexural strength values. Tests performed after 7, 28, and 56 days of cast date.

4. Test Results and Discussions

The results of this study derived in terms of slump test for fresh concrete and in terms of compressive strength, indirect tensile (splitting) strength, and flexure strength of the hardened concrete.

4.1. Effect of using (PEG 400) as self-curing agent

The slump test values increased when the dose of (PEG400) increased as shown in Table 9. The effect of using PEG400 on the mechanical properties of the hardened concrete second group is shown in Table 9 and Figs. 2-7.

The specimens which cured traditionally (immersed in water) as control specimens recorded a compressive strength of 33.18 MPa at 28 days. The optimum dosage of PEG is 4% in the specimens (SE4) with a compressive strength of 35.64 MPa at 28 days' tests. The specimens with PEG (SE4) records greater strengths at 28 days than control specimens by about 7.4%, 11.70%, and 3.80% respectively, for compressive strength, indirect tensile strength, and flexural strength. The strength of the specimens (SE4) greater than that recorded for none cured (NC) at age of 28 days by 37.80%, 38.70 % and 39.90% respectively, for compressive, indirect tensile and flexural strengths. The optimum compressive strength value obtained at a dosage of 4.0% PEG which nearly agreed with previous researches (Yehia, 2010; Emam, 2012). Compressive strength values of control specimens at age of 56 days increase by about 58.50% and 11.20% for (NC) and (SE4) specimens, respectively. That may because of the presence of silica fume in the concrete mixture, which improves the strength to the concrete at the later ages. Practically, the performance of concrete mix (SE4) is better than that of control specimens at age 56 days in the case of the presence of difficulties in curing processes in the field.

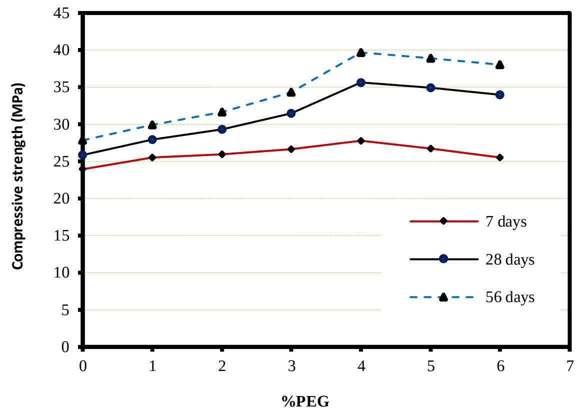

Fig. 2. Compressive strength values of the specimens versus the variable dosages of (PEG) as self-curing agent.

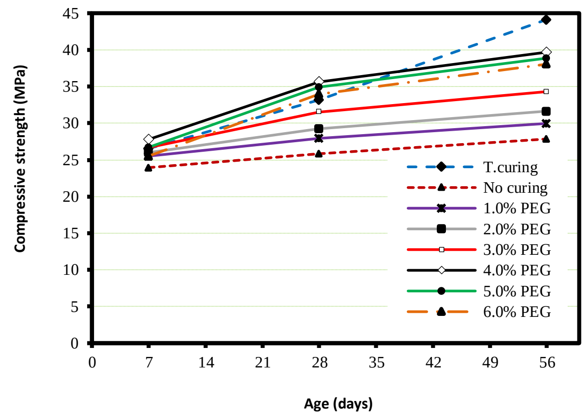

Fig. 3. Compressive strength values of concrete specimens cured by (PEG) as self-curing agent during early ages.

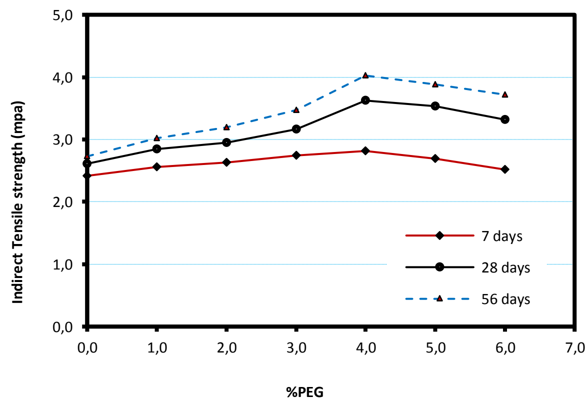

Fig. 4. Indirect tensile strength values of the specimens versus the variable dosages of (PEG) as self-curing agent.

Table 9. Concrete specimens and their main properties.

Group	Mix Code	Identification	Slump Test (mm)	Test Age (day)	Density (t/m³)	Comp-Strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)
A	TC	Traditional curing	56	7	2.50	26.54	2.62	2.73
				28	2.50	33.18	3.24	3.41
				56	2.48	44.13	4.22	4.50
	NC	Non -cured	56	7	2.46	23.94	2.42	2.31
				28	2.41	25.86	2.61	2.53
				56	2.36	27.84	2.73	2.76
B	SE1	Cured by 1% of cement weight PEG as self-curing agent of cement content	60	7	2.52	25.51	2.55	2.52
				28	2.52	27.91	2.85	2.82
				56	2.47	29.96	3.03	2.97
	SE2	PEG 2%	64	7	2.54	26.00	2.63	2.64
				28	2.52	29.28	2.95	3.00
				56	2.49	31.64	3.19	3.21
	SE3	PEG 3%	70	7	2.53	26.68	2.74	2.70
				28	2.52	31.52	3.17	3.20
				56	2.50	34.31	3.47	3.47
	SE4	PEG 4%	76	7	2.55	27.79	2.82	2.79
				28	2.52	35.64	3.62	3.54
				56	2.52	39.68	4.03	3.77
	SE5	PEG 5%	80	7	2.50	26.72	2.69	2.67
				28	2.50	34.95	3.53	3.49
				56	2.46	38.87	3.89	3.72
	SE6	PEG 6%	87	7	2.52	25.52	2.52	2.55
				28	2.50	33.95	3.32	3.34
				56	2.49	38.05	3.72	3.55
C	SA1	PAM 0.01%	55	7	2.53	26.85	2.78	2.55
				28	2.52	32.77	3.06	3.00
				56	2.50	33.53	3.40	3.24
	SA2	PAM 0.02%	49	7	2.49	24.45	2.50	2.40
				28	2.48	28.44	2.95	2.79
				56	2.48	29.11	3.25	3.06
	SA3	PAM 0.03%	45	7	2.45	20.74	2.20	2.01
				28	2.43	23.82	2.37	2.31
				56	2.40	24.22	2.51	2.55
D	SEA1	PEG+PAM 1.0%+0.01%	58	7	2.44	37.44	3.58	3.66
				28	2.42	44.86	4.46	4.35
				56	2.40	45.84	4.55	4.71
	SEA2	PEG+PAM 1.0%+0.02%	56	7	2.48	30.33	2.95	2.94
				28	2.46	43.17	4.22	3.84
				56	2.45	44.01	4.31	3.94
	SEA3	PEG+PAM 1.0%+0.03%	54	7	2.50	22.59	2.22	2.25
				28	2.48	25.10	2.47	2.46
				56	2.48	25.89	2.56	2.67

SE : Self-curing concrete mixture with Polyethylene glycol (PEG) as self-curing agent
SA : Self-curing concrete mixture with Polyacrylamide (PAM) as self-curing agent
SEA : Self-curing concrete mixture with combination of Polyethylene glycol +Polyacrylamide (PEG + PAM) as self-curing agent.

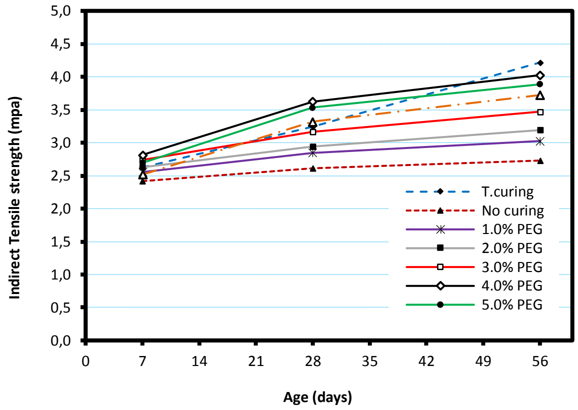

Fig. 5. Indirect tensile strength values of specimens cured by (PEG) as self-curing agent during early ages.

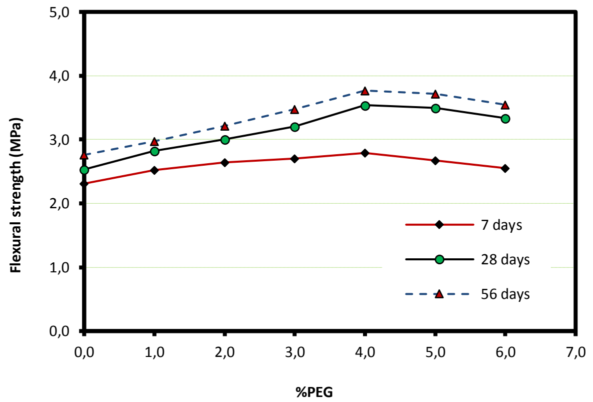

Fig. 6. Flexural strength values of the specimens versus the variable dosages of (PEG) as self-curing ages.

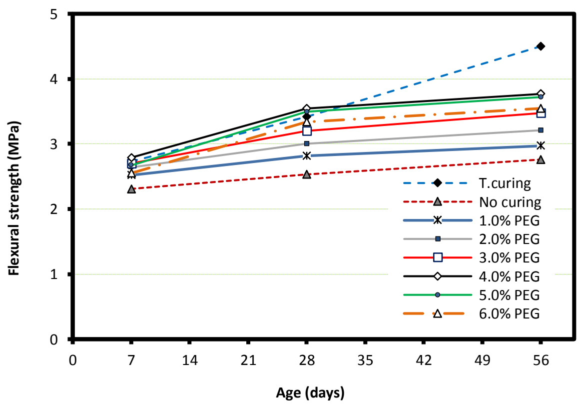

Fig. 7. Flexural strength values of concrete specimens cured by (PEG) as self-curing agent during early ages.

4.2. Effect of using (PAM) as self-curing agent

The slump test values (the fluidity) decreases initially, then increases, and decreases again with increasing PAM and the concrete mixture become sticky as shown in Table 9. That may because of the water-absorption effect of PAM, as well as the lubrication effect of the formed latex around cement particles (Sun and Xu, 2008). The effect of using PAM on the mechanical properties of hardened concrete (group C) are shown in Table 9 and Figs. 8-13. The optimum dosage of PAM is 0.01% (specimen SA1) which records a compressive strength value of 32.77 MPa at age of 28 days. The specimens cured by the optimum dosage of PAM (SA1) records strength less than control specimens (TC) at age of 28 days by 1.3%, 5.60% and 12%, respectively for compressive, indirect tensile and flexural strengths. The strength values of the specimens (SA1) are greater than that for none cured specimens (NC) at age of 28 days by about 26.70%, 17.24% and 18.57%, respectively for compressive, indirect tensile and flexural strengths. When the dosage of PAM increased more than 0.01% the strength of concrete decreased. It's noticed that the using of optimum dosage from PAM as self-curing agent in concrete specimens produced a compressive strength values less than that for cured by optimum dosage from PEG (SE4) by about 15.5 % at the age of 56 days and less than traditionally cured (TC) by 24% at the same age. That may results from the water-absorption effect of PAM compared to PEG.

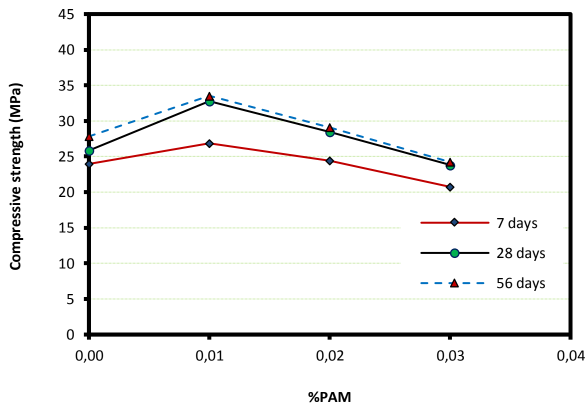

Fig. 8. Compressive strength values of the specimens versus the variable dosages of self-curing agent (PAM).

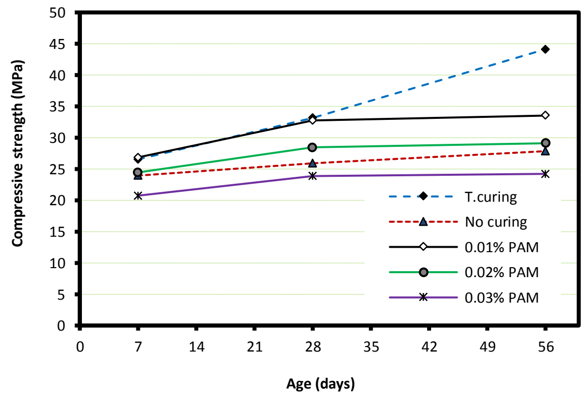

Fig. 9. Compressive strength values of concrete specimens cured by (PAM) as self-curing agent during early ages.

4.3. Effect of using a mix of PEG 400 and PAM as self-curing agents

The slump test values decreased when the dose of (PAM) increased as shown in Table 9. The effect of using a combination of both (as 1.0%PEG400 + PAM) on the mechanical properties of the hardened concrete (group D) are shown in Table 9 and Figs. 14-19.

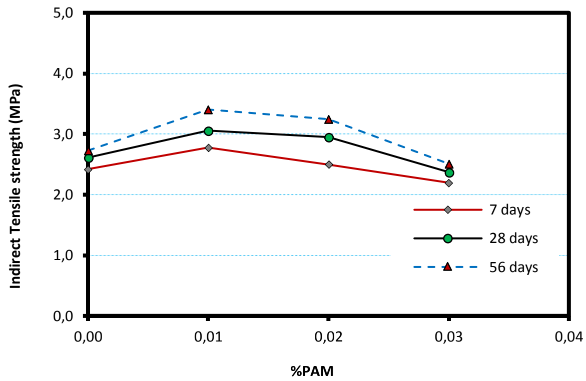

Fig. 10. Indirect tensile strength values of the specimens versus the variable dosages of (PAM) as self-curing agent.

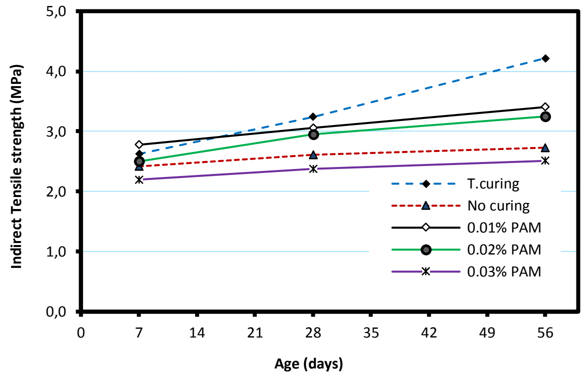

Fig. 11. Indirect tensile strength values of concrete specimens cured by (PAM) as self-curing agent during early ages.

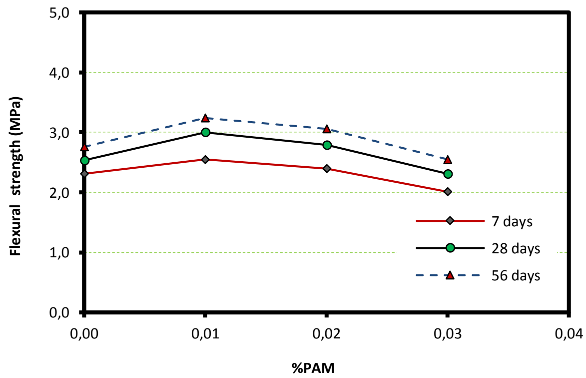

Fig. 12. Flexural strength values of the specimens versus the variable dosages of (PAM) as self-curing agent.

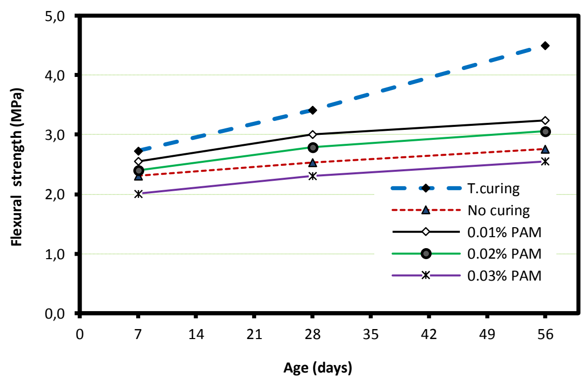

Fig. 13. Flexural strength values of all concrete specimens cured by (PAM) as self-curing agent during early ages.

The optimum dosage is at (0.01%PEG+0.01%PAM) in the specimens (SEA1) which records 44.86 MPa in compressive strength at age of 28 days. This specimen cured by the optimum dosage of the mixture (SEA1) records strength greater than control specimens (TC) at age of 28 days by 35.20%, 37.65% and 27.56%, respectively for compressive, indirect tensile and flexural strengths. The strength of the specimens (SEA1) is greater than that for none cured specimens (NC) at the age of 28 days by 73.47%, 70.88% and 71.93%, respectively for compressive, indirect tensile and flexural strengths.

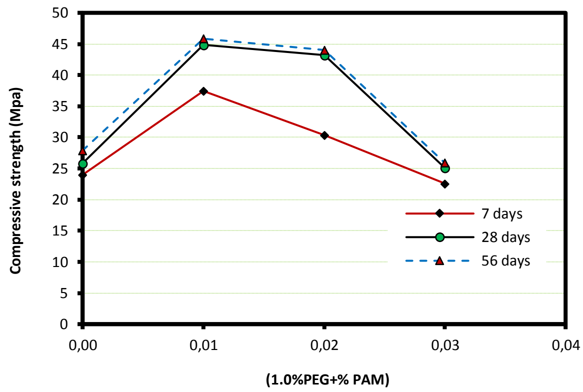

Fig. 14. Compressive strength values of the specimens at different dosages of (PEG+PAM) as self-curing agent.

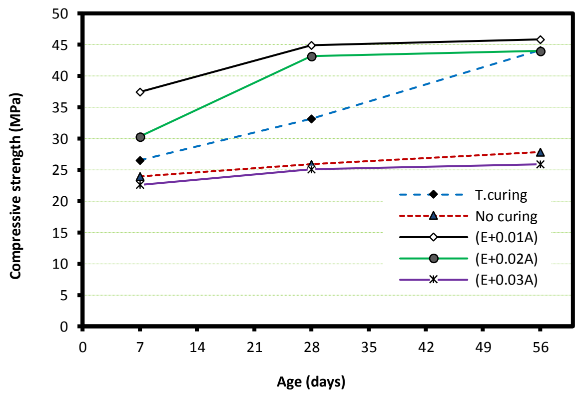

Fig. 15. Compressive strength values performance when cured using a mix of (PEG+PAM) as self-curing agent during early ages.

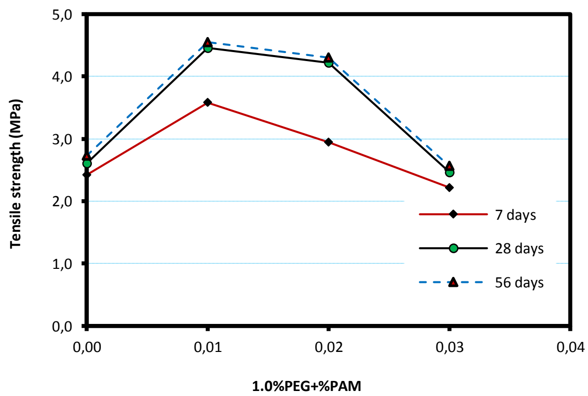

Fig. 16. Indirect tensile strength values of the specimens at different dosages of (PEG+PAM) as self-curing agent.

The compressive strength values decreased for dosages over 0.01% PAM at all ages. It is noticed that the using of optimum dosage from the mixture of (1.0%PEG400+PAM) as self-curing agent in concrete specimens gives compressive, indirect tensile, and flexure strength greater than that recorded for specimens cured by optimum dosage from PEG or PAM individually and greater than that traditionally cured also at all ages. That may result from the dual effect of each curing agent used which causes absorbing water, filling pores, forming polymer films over hydrates, and interacting with hydration process.

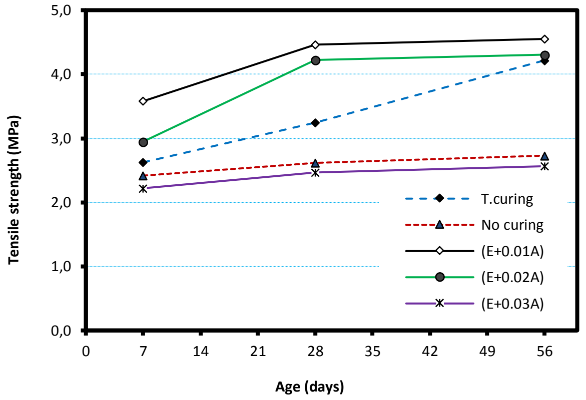

Fig. 17. Indirect tensile strength values when cured using a mix of (PEG+PAM) as self-curing agent during early ages.

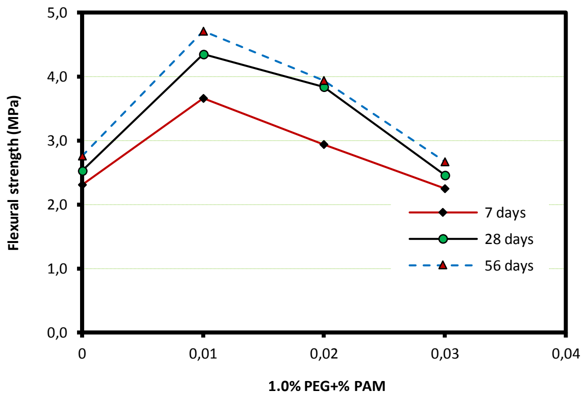

Fig. 18. Flexure strength values of the specimens at different dosages of (PEG+PAM) as self-curing agent.

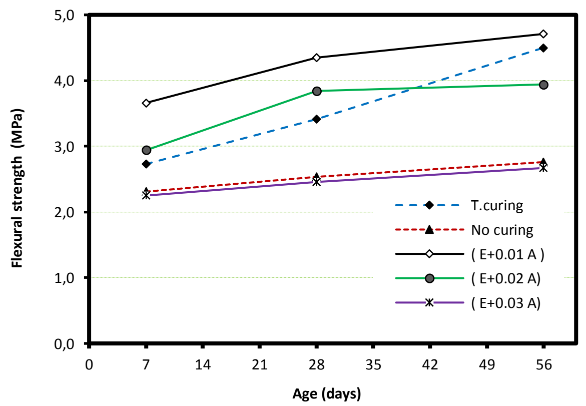

Fig. 19. Flexural strength values when cured using a mix of (PEG+PAM) as self-curing agent during early ages.

5. Conclusions

In this study, a series of experiments has been performed to investigate the behaviour and the properties of self-curing concrete specimens that cured by chemical self-curing admixtures. Comparison between self-curing concrete, traditional (cured in water), and none cured concrete has been done. Based on the experimental results presented in this paper, the conclusions could be drawn as follow:

- Using PEG400 or PAM is efficient to obtain SC concrete (in the range of this study).
- The slump values increased as increasing the content of PEG 400 while the slump values decreased as increasing the PAM content (in the range of this study).
- The optimum dosage when using PEG400 is 4% of cement content to obtain SC concrete.
- The optimum dosage when using PAM is 0.01% of cement content.
- The mechanical properties of the hardened concrete with the optimum dosage of PEG400 perform better than that used with the optimum dosage of PAM at the same ages.
- When mixing the two chemical curing agents used as 1.0%PEG400+0.01%PAM, the mechanical properties of SC concrete significantly improved compared to using each of PEG400 or PAM individually at all ages.

Generally, using PEG and PAM is efficient as a chemical self-curing agent to produce SC concrete with satisfied characteristics. Using a combination of PEG and PAM enhance the concrete strength with less cost as the PEG dosage decreased from 4.0% to 1.0% (which considered an expensive material) while PAM is cheaper material and its dosage is very small. That can be applied to cast self-curing concrete in poor water areas.

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