EFFECT OF STEAM CURING BY SOLAR ENERGY ON THE MECHANICAL STRENGTH AND DURABILITY OF CONCRETES

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ABSTRACT: The influence of atmospheric steam curing by solar energy on the mechanical strength for precast concrete elements was investigated. An experimental program was carried out to study in parallel the effect of water/cement ratio (0.4, 0.5 and 0.6), the influence of cement type and the influence of curing methods (four methods of curing were used: water curing, air curing, steam curing at 29°C and steam curing at 45°C) on the compressive and flexural strength of samples concrete. Six similar formulations of workability are made from ordinary Portland cement (CEM I 42.5) and a compound cement (CEM II/B 42.5), three of each type are studied. The results obtained flow highlight the beneficial effect of a steam curing procedure to achieve high compressive and flexural strength, especially in the earlier ages of curing. However, after 28 days of steam curing, a strength reduction was observed in all samples.

Key words: concrete, mechanical strength, steam curing, solar energy, precast elements.

INTRODUCTION

Atmospheric steam curing is a heat treatment which has been used for many years to accelerate the strength development of precast concrete products. Because of the hydration rate of cement increases with the increase in temperature, the gain of strength can be speeded up by curing concrete in steam. When steam is generated in atmospheric pressure, the temperature is below 100 °C; the process can be regarded as a special case of moist curing in which the vapour-saturated atmospheres ensures a supply of water (Hanson J.A.1963 and Neville A.M.1981).
It is confirmed that the steam curing at low pressure could improve the quality of high performance concrete incorporating mineral admixtures, comparing with standard curing (Maltais Y et al. 1997).

The curing temperature will be a compromise between rate of strength gain and ultimate strength, because of the higher, the curing temperature, the lower and the ultimate strength (Mindess et al. 1981).

The primary factors determining the behavior of cements subjected to heat treatment are fineness and composition of cements, the type and amount of additives used in blended cements and curing cycle parameters. For compressive strength development of concrete, duration of steam curing is also an important parameter as well as temperature (Oztekin E. 1984).

Erdem et al. (2003) concluded that in the delay in the commencement of steam curing operation by a period equal to the initial setting time of cement, higher strengths were obtained when the delay period was equal to the setting time. However, it is clear that the effect of the humidity during curing is a major consideration that cannot be ignored. Steam curing continues until the minimum is reached strength deemed essential to the performance of the element after demolding (Vénuat M. 1989), this minimum would be difficult to determine a priori because it depends on the shape more or less massive parts, and depends on the nature of the stresses to which they submitted after release. To fix ideas, we may admit that in the absence of any external load, the minimum strength to compressive should be located around 50 to 60% of the required strength (at 28 days under natural conditions) is 10 MPa (ACI 517.2R-87. 1992), which can transport and store the parts in concrete rooms for a natural hardening to ambient air in the realization of business without breaking.

The required objective is to evaluate through experiments the influence of atmospheric steam curing on the mechanical strength of concrete.

Experimental Program

In this section we present the materials used, formulation of concrete and the preparation of specimens.

Materials

Cement

The cement that was used is composed Portland cement CEM II/B 42.5 (Biskra - Algeria). Fineness = 3300 cm^2/g, apparent density = 1215 kg/m^3 and specific density = 3150 kg/m^3.

Water

The water is drinking water and having a temperature of 20 ± 1°C. Its quality conforms to the requirements of standard NFP 18-404.

Sand

The sand used is from the region of Biskra (Algeria). The grading curve of sand is given in fig.1. Apparent density = 1630 kg/m^3. Specific density = 2650 kg/m^3, Fineness modulus = 2.82

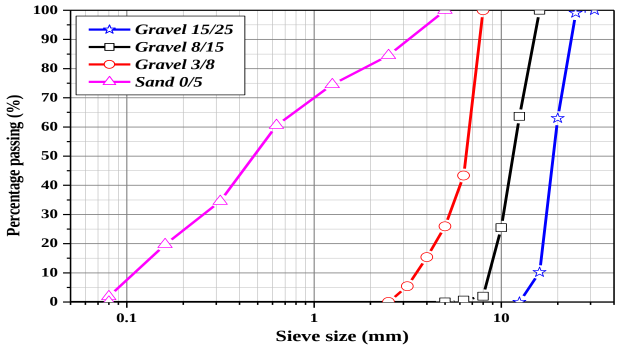


Figure 1. Grading Curve Of Sand And Crushed Stone

Crushed stone

We used crushed stone (CS) fraction 3/8, 8/15 and 15/25 mm of the region Batna in Algeria. The grading curve of crushed stone is given in figure 1, Apparent density = 1340 kg/m^3, Specific density = 2610 kg/m^3.

Study of the temperature in the steam curing chamber and at ambient air

Our study is first to raise the temperatures in the open air using a thermometer and within the confines of conservation (Figure 2) by other thermometers hourly and daily same time of 07 h to 21 h for 12 months of the year, the average of these monthly records are illustrated in figure 3.

Figure 2. Steam Curing Chamber

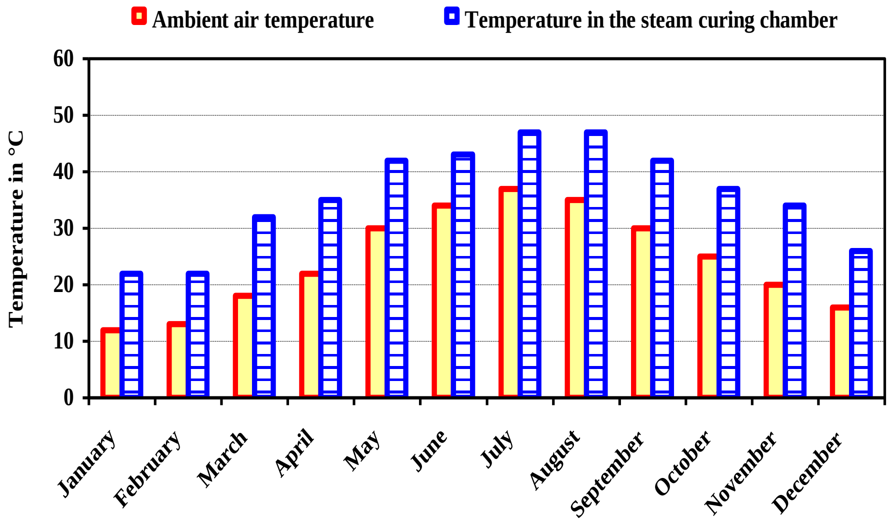


Figure 3. Monthly Exchange In Outdoor Temperatures And The Steam Curing Chamber

Formulation of concrete

Optimizing the formulation of concrete based on several criteria that are often a compromise between them: consistency, strength, durability and economy. Before the multiplicity of methods used to determine the composition of concrete was used that gives accurate results and seems to be the least known. This is the method of B. Scramtaiv. Whose consistency is such that its cone slump of 7 cm. In all tests the w/c = 0.4, A = 0.6, D_{max} = 25 mm and S/CS = 0.33. The composition of concrete is reported in table 1.

Table 1. Composition of Concrete (kg/m^3)

Cement	Sand	Crushed stone (7/15)	Crushed stone (15/25)	Water
512	407	432	802	205

From the graphs of the temperature variation with time of 12 months, we can say that for six months from April to September, the average temperature coefficient (K_1 = 1.70), and October to March, the average temperature coefficient is: (K_2 = 1.40). With: T° is the temperature in °c and K: the average temperature coefficient (K = 1.55). Based on the findings deduced from the variation curves of temperature versus time inside the chamber, we select the six months which corresponds to the seasons: spring and summer as shown in Table 2.

Table 2. Steaming Cycles And Maximum Temperatures In The Room (Spring-Summer)

Month	Apr	May	Jun	Jul	Aug	Sept
Cycles	3×8×3	3×8×3	3×8×3	3×9×3	3×9×3	3×8×3
Max. T°	38	43	44	46	48	43

We opt for steam curing cycle 1: (3×8×3) with a maximum temperature bearing 45 °c. We do the same for the other six (06) months representing the fall and winter and the pattern of the cycle.

Table 3. Steaming Cycles And Maximum Temperatures In The Room (Autumn - Winter)

Month	Oct	Nov	Dec	Jan	Feb	Mar
Cycles	3×8×3	3×7×3	3×7×3	3×7×3	3×7×3	3×8×3
Max. T°	34	32	30	28	23	34

We opt for steam curing cycle$_2$: (3×7×3) with a maximum temperature bearing 29°c.

Preparation of specimens

The strength is expressed by the power of concrete to resist destruction under the action of stresses due to different compressive loads and flexural.
Specimens of cubic (100×100×100 mm) were produced to determine the compressive strength, other form of prismatic (100×100×400 mm) to determine the flexural strength.
The concretes studied: a control concrete stored in water at an ambient temperature of 20 ± 1°c, concrete cured outdoors without irrigation, and concretes subjected to two cycles of steam curing.
The steam curing cycle must include four phases: delay period; temperature rises; maximum temperature and cooling.
After mixing the concrete, the specimens are preserved in plastic to prevent evaporation of water from the concrete, after demolding, the specimens are introduced into the steam curing chamber by solar energy with the rise of the temperature in the chamber, the thermometer was placed outside of the chamber can adjust the temperature level selected at 45°c in the chamber for the warm period of the year.
(6 months from October to March) and 29°c for the cold period (6 months from April to September), for durations of steam curing 1, 2, 3 and 7 days hardening in open air without spraying of 3 and 7 days.

RESULTS AND DISCUSSIONS

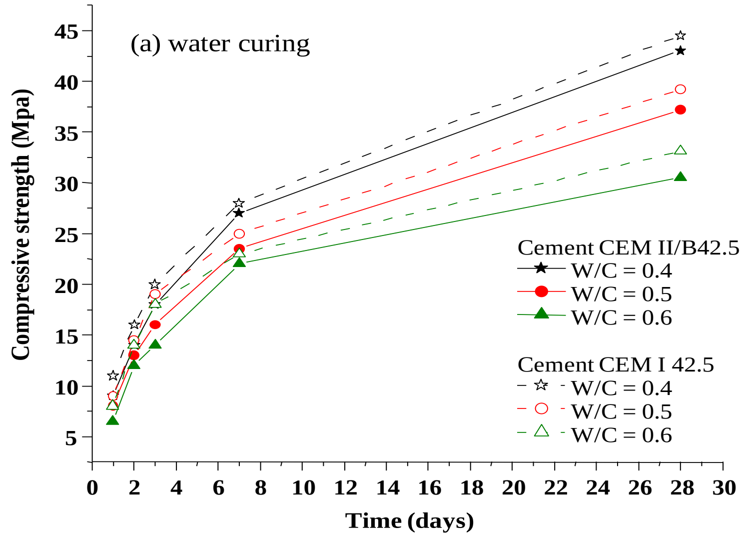
Consistency

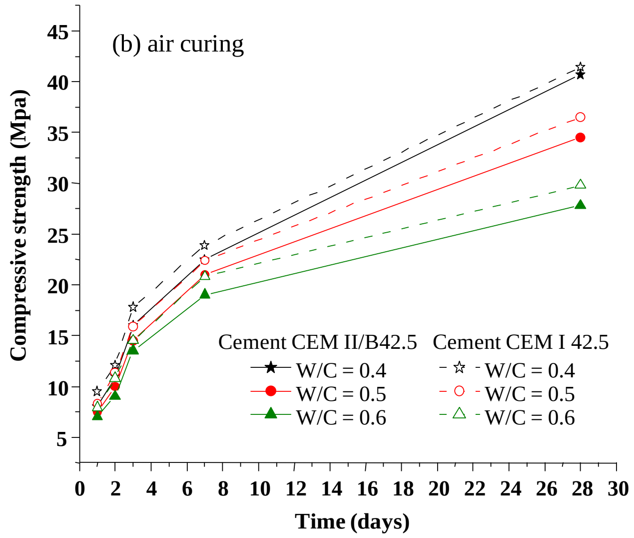
It is important to know the properties of concrete in fresh state before setting and hardening. Among these properties, consistency can be defined as the ease of implementation of concrete.
The slump test to Abrams cone NF P 18-451 is currently in use worldwide. Depending slump obtained, class consistency of different concrete is plastic (slump varies from 6 to 8 cm).

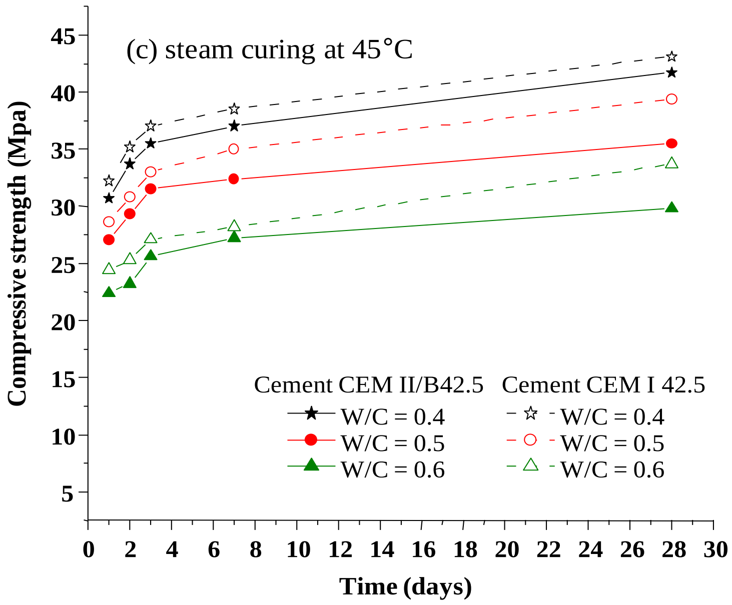
Compressive and flexural strength

The strengths are estimated at 1, 2, 3 and 7 days of steam curing, 28 days in wet and dry.

The results of compressive and flexural strength of concrete in water, the open air and concretes having undergone a steam curing are given in figure 4 (a, b, c and d), 5 and 6 respectively.






(c) steam curing at 45°C
Compressive strength (Mpa)
Time (days)
Cement CEM II/B42.5
Cement CEM I 42.5
W/C = 0.4
W/C = 0.5
W/C = 0.6
W/C = 0.4
W/C = 0.5
W/C = 0.6

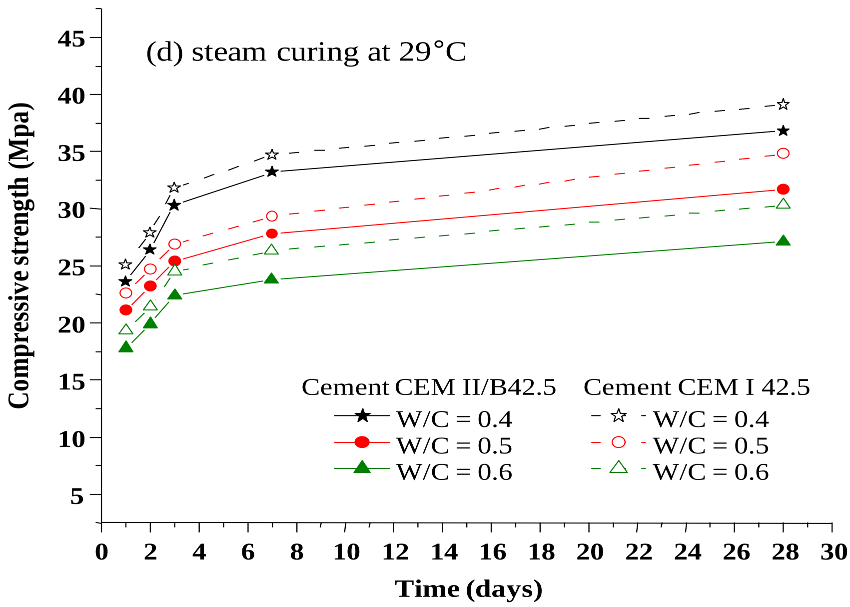
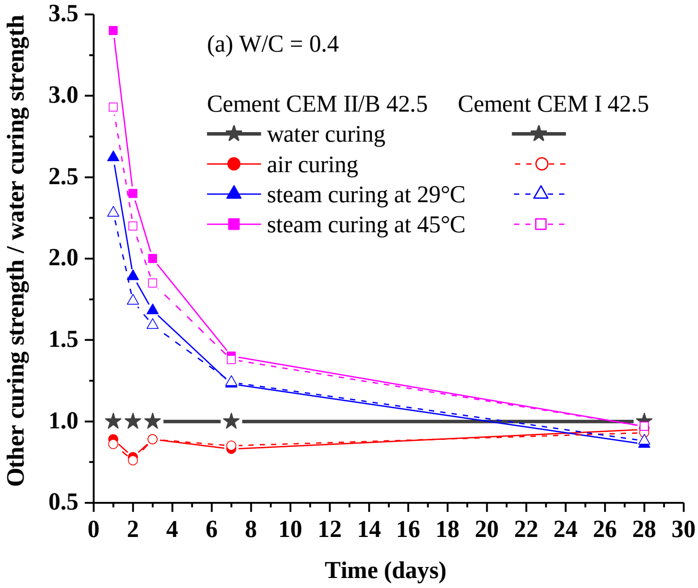
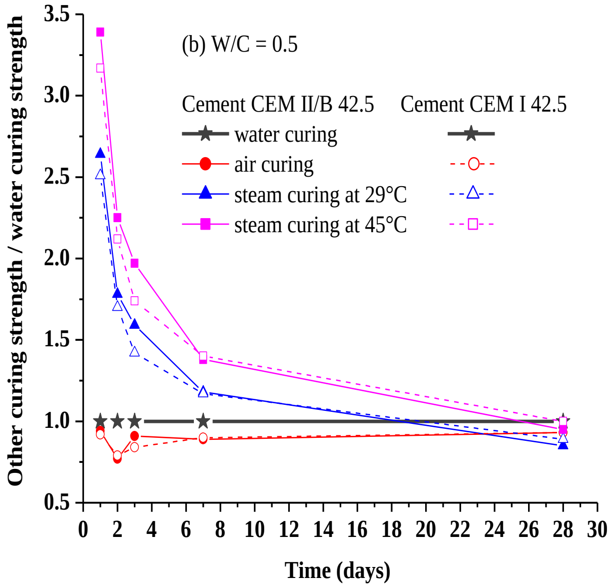

(d) steam curing at 29°C
Compressive strength (Mpa)
Time (days)
Cement CEM II/B42.5
Cement CEM I 42.5
W/C = 0.4
W/C = 0.5
W/C = 0.6
W/C = 0.4
W/C = 0.5
W/C = 0.6

Figure 4. Effects Of Curing Methods, Cement Type And W/C Ratio On The Compressive Strength Development Of Samples





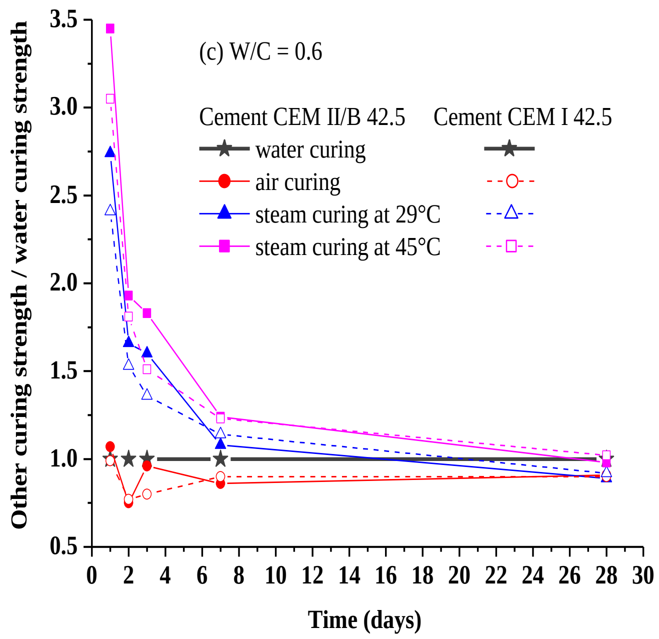
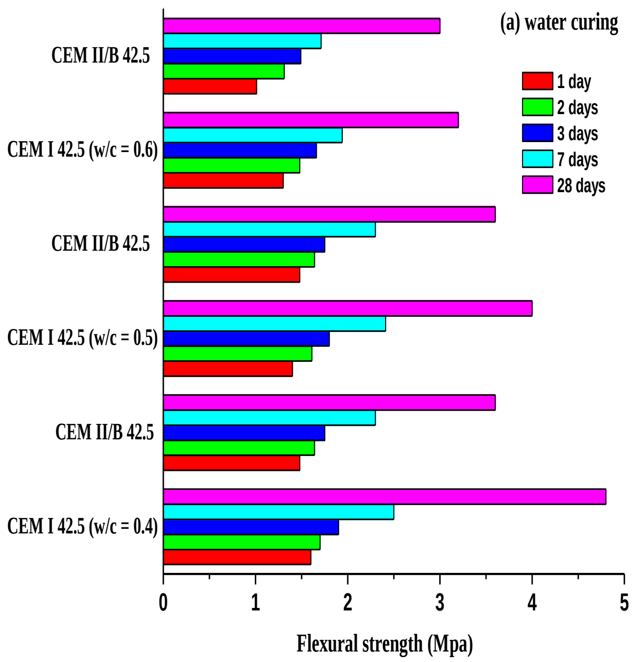
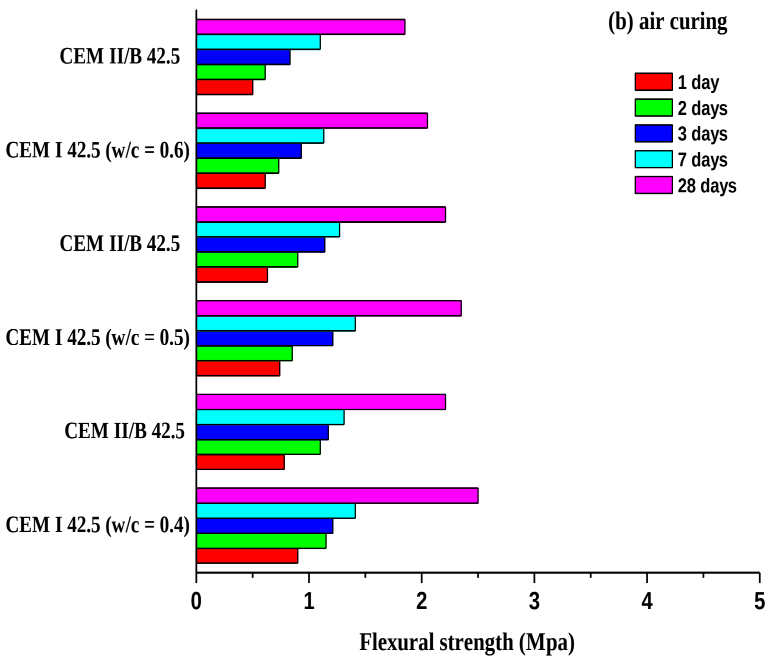
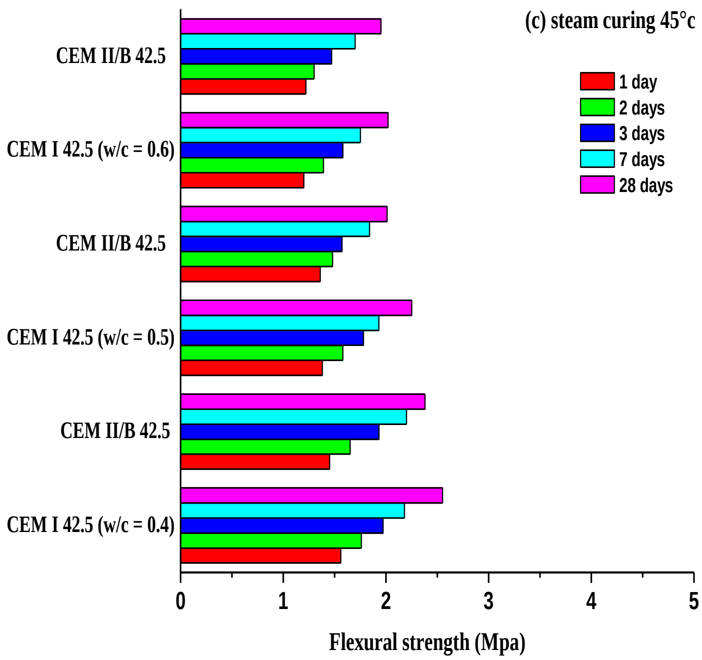


Figure 5. Effects of Curing Methods, Cement Type And W/C Ratio On The Compressive Strength Ratio Of Samples




(b) air curing
1 day
2 days
3 days
7 days
28 days
CEM II/B 42.5
CEM I 42.5 (w/c = 0.6)
CEM II/B 42.5
CEM I 42.5 (w/c = 0.5)
CEM II/B 42.5
CEM I 42.5 (w/c = 0.4)
0
1
2
3
4
5
Flexural strength (Mpa)


(c) steam curing 45°c
1 day
2 days
3 days
7 days
28 days
CEM II/B 42.5
CEM I 42.5 (w/c = 0.6)
CEM II/B 42.5
CEM I 42.5 (w/c = 0.5)
CEM II/B 42.5
CEM I 42.5 (w/c = 0.4)
0
1
2
3
4
5
Flexural strength (Mpa)

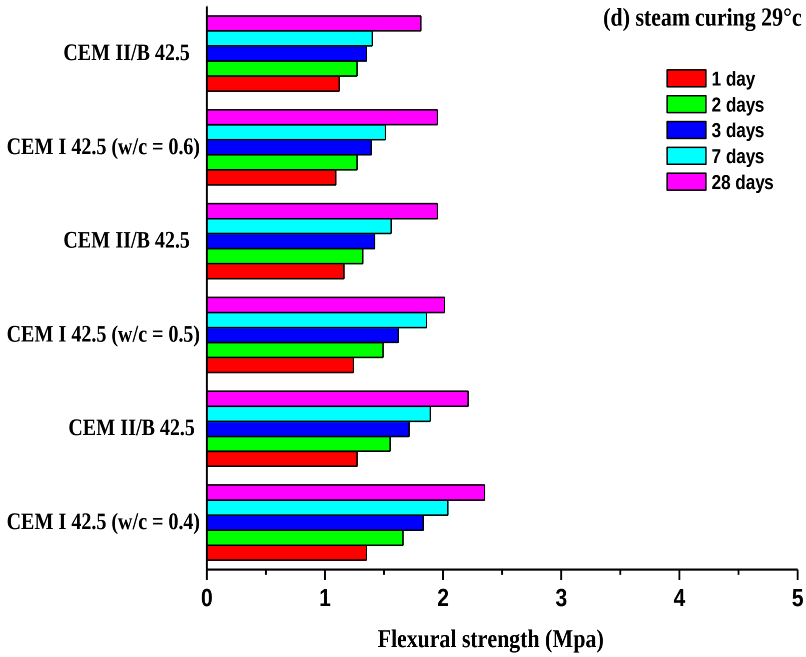


Figure 6. Effects Of Curing Methods, Cement Type And W/C Ratio On The Flexural Strength Development Of Samples

Extension of hardening of concrete in the open air

One day of steam curing at 45°c and hardening of 3 and 7 days

The strengths estimated from (1d steam curing and air 3d) and (1d steam curing and air 7d) for steam curing at 45°c are shown in table 4.

Table 4. Compressive And Flexural Strength Of Concrete (1d Steam Curing At 45°C + Air 3 And 7d)

Strength (MPa)	1d steam curing + air 3d	(%) harden	1d steam curing + air 7d	(%) harden
Compressive	40	99	43	105
Flexural	1.80	82	2.00	90

The period (spring - summer) at 45°c, the months of April-September results show that treatment with steam curing in the chamber ensures a rapid increase in compressive strength for: 1, 2, 3 and 7 d of steam curing at 45°c, are: 30.7, 33.7, 35.5 and 37.0 MPa, which are: 75, 83, 87 and 91% of the strength of hardened concrete even under natural conditions to 28 days respectively.

- Compressive strength of one day steam curing at 45°c (08 h of oven) and in air 3 and 7 d under natural conditions, which are: 40.3 and 43 MPa, are: 99 and 105% of

the strength of the hardened concrete even under ambient conditions at 28 days respectively.
- An increase in compressive strength and flexural strength versus time, which ensures demolding of the molds only 3 days in air.

One day of steam curing at 29°c and hardening of 3 and 7 days

The strengths estimated after (1d of steam curing and air of 3d) and (1d of steam curing and air 7 d) for steam curing at 29°c are shown in Table 5.

Table 5. Compressive And Flexural Strength Of Concrete (1d Of Steam Curing At 29°C + Air 3 And 7d)

Strength (MPa)	1d steam curing + air 3d	(%) harden	1 d steam curing + air 7d	(%) harden
Compressive	39.30	96.50	41	100
Flexural	1.43	64.70	1.62	73.30

The period (autumn - winter) at 29°c, for the months of October to March:
- One day of steam curing at 29°c: 23.6 MPa, which shows: 58% of the strength of hardened concrete even under natural conditions to 28 days.
- One day steam curing concrete at 29°c (08 h of steam curing) and in air 3 d under natural conditions, which presents: 39.3 MPa, or 96.5% of the strength of hardened concrete even under natural conditions to 28 days.
- One day steam curing concrete at 29°c and 7 days of hardening under natural conditions, which presents: 41.0 MPa, 100% of the strength of hardened concrete even under natural conditions to 28 days.
- An increase in compressive and flexural strength as a function of time, which ensures demolding of the molds only in 3 days in air.

Mass loss in the steam curing chamber at 45°c and 29°c

The quantification of the wastewater between the demoulding and the sample removal in the stoving chamber was carried out using a balance with a capacity of 10 kg and an accuracy of 0.01 g used for the determination of The mass of the specimens before and after the two cycles of hardening and curing in ambient air.
The results presented in Tables 6 and 7 indicate that the mass losses during stoving at 45 °C and 29 °C. between the demoulding and the test time for different ages of 3 and 7 of curing caused by the creation of very fine cracks By the expansion of the air bubbles in the cement and the evaporation of the water of the capillaries.

Table 6. Mass Loss In (gr) Of The Cubes And Prisms At 45°C

Specimens	air 28 d	Steam curing			
		1d	2d	3d	7d
Cubes	35	24	46	68	149
Prisms	110	90	130	185	240

Specimens	1d steam curing + air 3d	1d steam curing + air 7d
Cubes	30	45
Prisms	102	120

Table 7. Mass Loss In (gr) Of The Cubes And Prisms At 29°C

Specimens	air 28 d	Steam curing			
		1d	2d	3d	7d
Cubes	35	20	40	60	128
Prisms	110	80	120	175	220

Specimens	1d steam curing + air 3d	1d steam curing + air 7d
Cubes	27	40
Prisms	93	111

CONCLUSION

Add conclusions here. Add conclusions here. Add conclusions here. Add conclusions here. Add conclusions - The technique of steam curing is an effective technique for portlands cements for accelerated hardening of concrete.

- The demolding is assured after all steam curing at 45 or 29°c, since we met exceeds the minimum strength to compressive which is approximately 10 MPa after one day of steam curing, which ensures high productivity molds.
- We reached the 28 days strength after one day and 3 days of hardening in open air, for 2 types of steam curing, which has a gain of time and shorter manufacturing lead times.
- The plastic concrete works to heat treatment, for a temperature of 45°c in steam with 8 hours of heat treatment with a pre made, the strength reach 75% of the control concrete strength of 28 days of normal hardening, also the fall of mechanical strength at the age of 28 days of a concrete treated compared to concrete o f control is around 10%.
- This hardening technique in Algeria which is rich in solar energy and the use of this renewable energy in the heat treatment of concrete parts in areas with high radiation concentration and long periods, which reduces the cost of Concrete parts, resulting in a remarkable economy for production companies, as well as productivity changes for the concrete industry.

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