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# Performance of Cement Mortar Exposed to Different Temperature and Curing Methods

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**Abstract**

Curing is an important process to achieve the specified concrete strength and durability. The objectives here is to determine the effect of four curing regimes on the development of mechanical properties for mortar specimens with mix proportions of 1:2.75 cement to sand by mass with W/C of 0.46, and with standard cube and prism dimensions, using OPC and SRPC; specimens tested under curing temperatures at 25 °C and 45 °C; to simulate the seasonal climatic conditions in Iraq. Curing methods adopted were: 1st: immersion in water, 2nd: wetting by using saturated covers, 3rd: curing by using wax-based compound, and 4th: by air curing. The specimens were examined at the ages of 3, 7, 14, and 28 days for density and mechanical properties. The study highlights that fully-saturated specimens in water is the recommended curing; as test results indicate that the highest mechanical properties were obtained. Considering the compressive strength as the criterion, curing by using wax-based compound came 2nd; and curing by saturated covers in 3rd position. This is true for temperatures at 25 °C and 45 °C; however, the experiments carried on OPC mortar show that increasing the temperature from 25 °C to 45 °C increases the early strength at 3 and 7 days by 16% and 22%, respectively; while the strengths at 14 and 28 days indicate an opposite manner; as the strength decreases when comparing the testing results at those ages by 23% and 17%. This is also valid for SRPC mortar and water-immersion curing for the same temperatures and corresponding ages; 25% and 19% increase at 3 and 7 days, respectively; but the results show that there was a continuous increase in strength at 14 and 28 days, by 29% and 33%, respectively. The study points out that immersion-curing in high temperatures is not recommended for OPC mortars after the age of 7 days; while it could be used for SRPC mortars.

*Keywords:* Cement Mortar; OPC; SRPC; Temperature; Curing Methods; Compressive Strength; Density.

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## 1. Introduction

Concrete is one of the most constructive materials used in construction. It is subject to change in environmental conditions. Because of the heterogeneous nature of concrete, the mechanical and physical properties are widely varied and more complicated than most materials as those properties are thoroughly influenced by environmental conditions especially during the casting and curing periods [1].

Curing is the maintenance of satisfactory temperature and moisture content in concrete or cement mortar for a sufficient period of time after the pour and accelerating the hydration process of the cementitious material [2], hence the control of temperature variation and moisture movement is quite essential to produce high-quality concrete [3]. As

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reached by most researchers a curing stage of concrete is very important for its strength development and durability [4]. Due to exposure of concrete to environment conditions, evaporation of moisture occurs, and this will decrease the primary W/C ratio, which in turn results in incomplete hydration process of cement products and causes a reduction in the quality of concrete. Evaporation leads to plastic shrinkage in the initial stage and drying shrinkage in the final stage.

One of the most important factors that affect the development rate of the concrete strength is curing temperature. At high-temperature, concrete curing causes higher development rate of strength at an early stage, as compared to concrete cast and cured at a lower temperature, but strength is generally lowered at 28 days and later stage [5]. The non-cured concrete (air-cured) reduces the strength to more than fifty percent as compared to moist curing concrete. Yang et al [6] Founds that the Concrete curing at a high temperature about (40∘C) developed a strength about (1.03–1.19) times as Compared to concrete cured at the reference temperature (20∘C) and lower strength development when concrete is cured at the cold temperature (5∘C) by (1.0–4.5%).

There are two main methods for curing concrete: those that maintain the availability of water by continuous or frequent application of water through immersion. Steam, or wetting by using saturated covers such as burlap or mats, and those that minimize or prevention of excessive loss of water from exposed surfaces of concrete by sealing it’s using sheets of paper or plastic, or by application compounds of membrane-forming [7]. Curing efficiency is affected by two main factors, one of them curing techniques and the other curing duration. Different levels of efficiency and performance concrete depend upon the methods used in curing. The curing method effectiveness depends on curing materials, environmental conditions, type and method of construction.

A lot of research was done to determine the suitable curing method and many methods were suggested by researchers. Goel et al.,[8] found the immersion-in-water method is the most suitable curing method for concrete. Raheem et al.,[9] Were on the view that the moist sand curing method is the most suitable curing method for concretes. Nahata et al.,[10] found the compressive strength of specimens that cured by a membrane and saturated wet covering curing achieved about 80-90 % as compared to water immersion curing method, saturated wet covering is not convenient for high rise buildings. Concrete curing with wax-based curing compound and curing with acrylic resin-based compounds decreased flexural strength by 21% and 26% respectively as compared to water immersion curing [11].

Olofinnade et al.,[12] indicate that the concrete cured by immersion in water method gives better performance in the development of strength than the plastic membrane covering method. Prakash et al., [13] observed that the result of impact develop of concrete strength at 7 days gives optimum values in the case of water submerged curing than the other various techniques used. In the current study, the curing method with completely–immerged specimen in water was thoroughly investigated to evaluate the strength of cement mortar.

Jiji et al., [14] investigate that accelerated curing method achieved 90% of the compressive strength in 7 days, also they achieved that accelerated curing was more effective than carbonation curing in achieving durability properties of concrete. For this reason, carbonation method was not used in the current study. The accelerated curing method was adopted in the current study to achieve the maturity of cement strength by heating the specimens to 45 °C for the whole age of the testing specimens. Zeyad [15] evaluated the effect of hot weather on high strength concretes with and without polypropylene fibers that cured by wet cover and water spraying methods. The addition of polypropylene fibers to concrete mix reduces the effect of high temperature on concrete properties, so improve the compressive and flexural strengths.

The objectives of this study is to evaluate the development of mechanical properties for two types of mortars using ordinary-Portland-cement, OPC and sulfate-resisting-Portland-cement, SRPC, respectively, under the effect of four curing methods the 1st is immersion in water, the 2nd is wetting by using saturated covers, the 3rd is curing by using wax-based compound, and the 4th is by air curing and two temperatures (25 and 45 °C) .the specimen that used in this study with dimensions 50×50×50 mm for cubes and 40×40×160 mm for prism. The study also include the continues effect of rising temperature along the age of curing, this was done because of most days of summer season in Iraq is very hot, so causing disintegration of cement plastering used for finishing the building faces, when the plastering performed in high temperature.

## 2. Materials and Methods

The experimental program was planned in order to evaluate the properties of different cement mortars that were cured in different conditions and temperature.

Ordinary Portland cement and sulfate resisting Portland cement 42.5 grade produced in Iraq – Mass factory near Sulaymaniyah – were used throughout this investigation. The chemical composition and physical properties of these cement are presented in Tables 1-2, respectively, as the testing procedures were performed in accordance with ASTM C 150 [16] and (IQS No.5/1984) [17].

**Table 1. Chemical composition and main compounds of ordinary Portland cement and sulfate resistance Portland cement**

| Oxide Composition | Ordinary Portland Cement | | Sulfate Resistance Portland Cement | |
|---|---|---|---|---|
| | % by weight of cement | Limits of Iraqi specification No.5 [17] | % by weight of cement | Limits of Iraqi specification No.5 [17] |
| Lime (CaO) | 62.14 | - | 64.66 | - |
| Silica (SiO2) | 20.70 | - | 20.74 | - |
| Alumina (Al2O3) | 5.96 | - | 4.34 | - |
| Iron oxide (Fe2O3) | 3.34 | - | 5.17 | - |
| Sulfate (SO3) | 2 | ≤ 2.8% | 2.43 | ≤ 2.5% |
| Magnesia (MgO) | 3.94 | ≤ 5% | 1.97 | ≤ 5% |
| Loss on Ignition (L.O.I.) | 1.07 | ≤ 4% | 3.39 | ≤ 4% |
| Lime Saturation Factor (L.S.F.) | 0.90 | 0.66-1.02 | 0.94 | 0.66-1.02 |
| Insoluble residue (I.R.) | 0.60 | ≤ 1.5% | 0.93 | ≤ 1.5% |
| **Main compounds (Bogues eq.)** | | | | |
| Tricalcium silicate (C3S) | 41.71 | - | 41.71 | - |
| Dicalcium silicate (C2S) | 27.88 | - | 27.88 | - |
| Tricalcium aluminate (C3A) | 10.64 | - | 2.76 | - |
| Tetracalcium aluminoferrite (C4AF) | 10.16 | - | 10.16 | - |

**Table 2. Physical properties of ordinary Portland cement and sulfate resistance Portland cement.**

| Physical properties | Ordinary Portland Cement | | Sulfate Resistance Portland Cement | |
|---|---|---|---|---|
| | Test result | Limits of Iraqi specification No.5 [17] | Test result | Limits of Iraqi specification No.5 [17] |
| Specific surface area, Blaine Method, ($m^2$/kg) | 313.1 | >= 230 $m^2$/kg | 373 | >= 230 $m^2$/kg |
| Setting time | | | | |
| - Initial setting(hrs.: min) | 90 | ≥ 45 min | 75 | ≥ 45 min |
| - Final setting(hrs.: min) | 2.5 | ≤ 10 hrs. | 4 | ≤ 10 hrs. |
| Compressive strength of mortar (MPa) | | | | |
| 3-days | 27.2 | ≥ 15 MN/$m^2$ | 29 | ≥ 15 MN/$m^2$ |
| 7-days | 35 | ≥ 23 MN/$m^2$ | 34 | ≥ 23 MN/$m^2$ |
| Soundness % (Autoclave) | 0.48 | ≤ 0.8 | 0.2 | ≤ 0.8 |

Natural sand used was locally sourced from Al- Obeidi quarry of sand. The sieve analysis and physical properties of the sand are in agreement with the limits specified by Iraqi standard (IQS No.45/1984) [18] as shown in Table 3 and figure 1. Normal tap water was used for mortar mixing in laboratory.

**Table 3. Grading and physical properties of fine aggregate**

| Sieve size (mm) | Passing% of sand | Limits of Iraqi specification No.45 [18] |
|---|---|---|
| 10 | 100 | 100 |
| 4.75 | 95 | 90-100 |
| 2.36 | 79.29 | 75-100 |
| 1.18 | 65 | 55-90 |
| 0.6 | 45.43 | 35-59 |
| 0.3 | 13.71 | 8-30 |
| 0.15 | 2.71 | 0-10 |
| **Physical properties of sand** | **Test result** | **Limits of Iraqi spec. No.45 [18]** |
| Fineness modulus | 2.9 | - |
| Specific gravity | 2.76 | - |
| Absorption | 1.2% | - |
| SO3 | 0.2 % | ≤ 0.5% |
| Dry rode density | 1680 kg/$m^3$ | - |

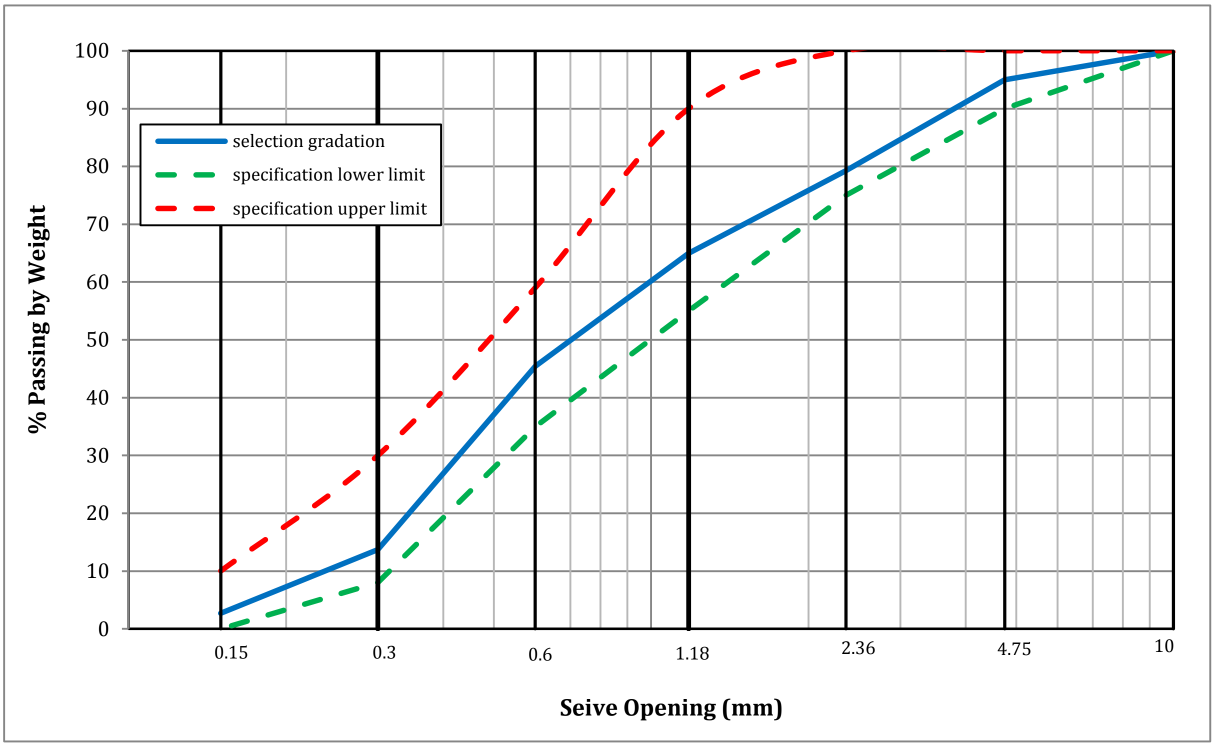


**Figure 1. Selected fine aggregate gradation and specification limits**

## 2.1. Mix Design

The mortars used to consist of 1: 2.75 cement/ sand by mass. Water to cement ratio is 0.46 which is enough to satisfy a flow of (110 ± 5mm) by 25 drops of the flow table test as per ASTM C 109. Test specimens are (50 mm cubes and 40×40×160 mm prisms) were prepared at laboratory conditions (20 °C) according to ASTM C 109 [19].

## 2.2. Methods of Curing

- Air curing: in this method the specimens were Leave in air to be cured naturally at (25 and 45 °C) until testing age.
- Immersion in water: Specimens were submerged in a water tank at (25 and 45 °C) and tested at target curing date.
- Saturated wet covering curing: used this method is usually in construction buildings. the most fabrics used for retaining moisture and keep the specimen in a wet condition are burlap cotton mats, gunny bag, and rugs; in this research, gunny bag was selected to cover the specimens until testing age.
- Curing compounds: Several types of curing compounds exist, they are applied on the exposed surfaces of concrete by helping of roller, brush, and spray. The product used in this research is Darakote 90WX, is a white emulsion based curing membrane which used to protect the hardened concrete surfaces from the undesirable effect of surface moisture evaporation.

## 2.3. Testing

Compressive, flexural Strengths and density testing's were processed on specimens with various ages at 3, 7, 14 and 28 days; and cured in different condition. Three cubes were tested under compression according to ASTM C 109 [19] and three prisms were tested under flexure (modulus of rupture) according to ASTM C 348 [20], to evaluate the modulus of rupture; finally averages values were obtained.

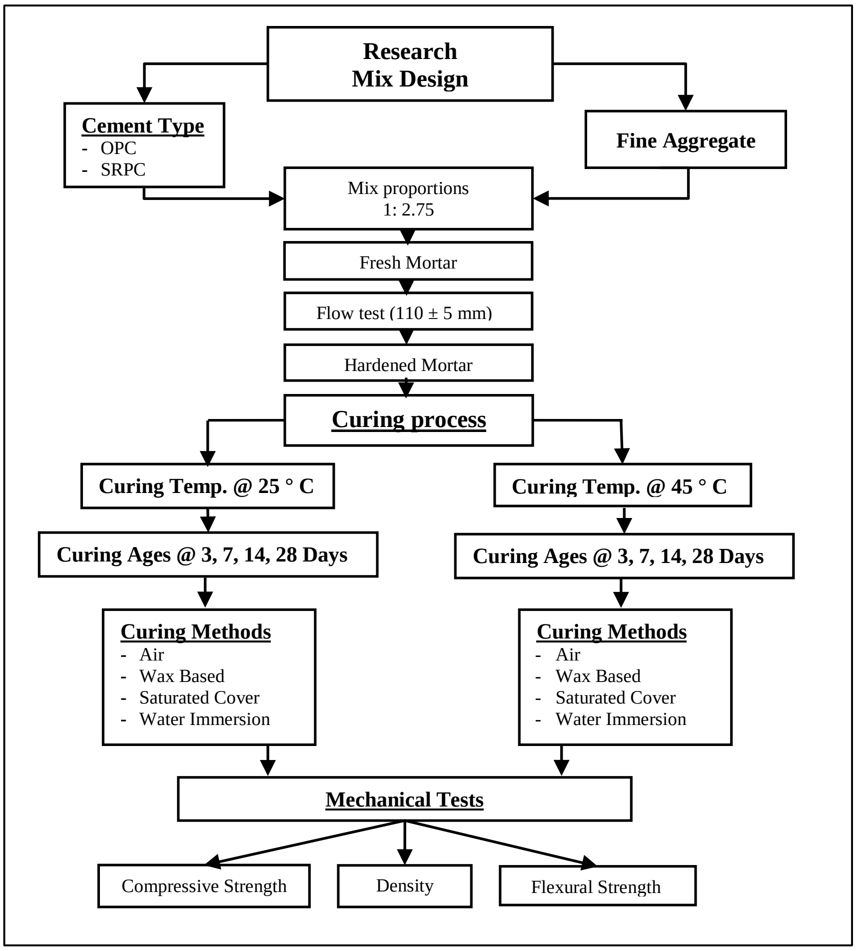


**Figure 2. Work program flowchart**

# 3. Results and Discussions

The experimental test results on the adopted program and the influence of curing methods and temperatures on the cement mortar properties are presented and discussed in the following sections.

## 3.1. Effect of Curing Method on Compressive Strength

The results obtained from experimental works including many parameters are carefully analyzed. Table 4, shows a summary of effect of curing method on the compressive strength of mortar specimen at the specified ages.

**Table 4. Compressive strength results for cube specimens made from two types of cement at different ages and curing method**

| Cement Type | Temp. | Curing Method | Compressive Strength (MPa) | | | |
|---|---|---|---|---|---|---|
| | | | 3 Day | 7 Day | 14 Day | 28 Day |
| OPC | Curing @ 25 °C | Air | 6.27 | 8.76 | 14.64 | 18.9 |
| | | Wax-Based Compound | 10.59 | 12.39 | 24.72 | 27.31 |
| | | Wetting Saturated Covers | 8.97 | 10.12 | 21.87 | 25.27 |
| | | Water Immersion | 14.07 | 16.15 | 26.81 | 31.31 |
| | Curing @ 45 °C | Air | 9.47 | 12.95 | 14.28 | 15.25 |
| | | Wax-Based Compound | 13.59 | 15.92 | 16.52 | 18.12 |
| | | Wetting Saturated Covers | 12.92 | 16.52 | 18.76 | 21.19 |
| | | Water Immersion | 16.32 | 19.76 | 20.52 | 25.8 |
| SRPC | Curing @ 25 °C | Air | 6.33 | 10.13 | 12.19 | 15.8 |
| | | Wax-Based Compound | 9.13 | 15.91 | 16.79 | 18.2 |
| | | Wetting Saturated Covers | 8.5 | 13.44 | 15.12 | 16.8 |
| | | Water Immersion | 13.12 | 17.01 | 18.13 | 20.04 |
| | Curing @ 45 °C | Air | 8.33 | 11.75 | 13.75 | 15.75 |
| | | Wax-Based Compound | 13.1 | 16.79 | 18.97 | 20.83 |
| | | Wetting Saturated Covers | 11.23 | 14.09 | 16.44 | 18.93 |
| | | Water Immersion | 16.44 | 20.17 | 23.53 | 26.87 |

### 3.1.1. Cement Mortar Containing OPC

Figure 3 shows the relation between the compressive strength of mortar specimens made with ordinary Portland cement, OPC and curing method at different ages.

The results indicate that the compressive strength obtained by using a water curing method is larger than that obtained by using other methods of curing. This is similar to the results obtained by [10] in which the compressive strength at 28 days by using water immersion and wax-based curing compounds is normally higher than that obtained by wet covering method. Air curing method has the lowest compressive strength at 28 days.

specimens cured by wax-based give a compressive strength close to water immersion curing method by 87.2 %, whereas the other two types of curing methods (wet covering and Air curing methods) have 80.7 and 60.3% as compared with water immersion curing at 25 °C curing temperature for 28 curing days. While at 45 °C of curing temperature the result of wax-based curing is near to wet covering curing and Possess compressive strength of 70.2 and 82.1% respectively as compared with water immersion curing at 28 days. This implies that the traditional method of curing by immersion of specimens in water is superior to the other methods.

This increase in compressive strength is due to the reaction between the water and cement particles which is more efficient for developing the strength than the other types of curing for all ages.

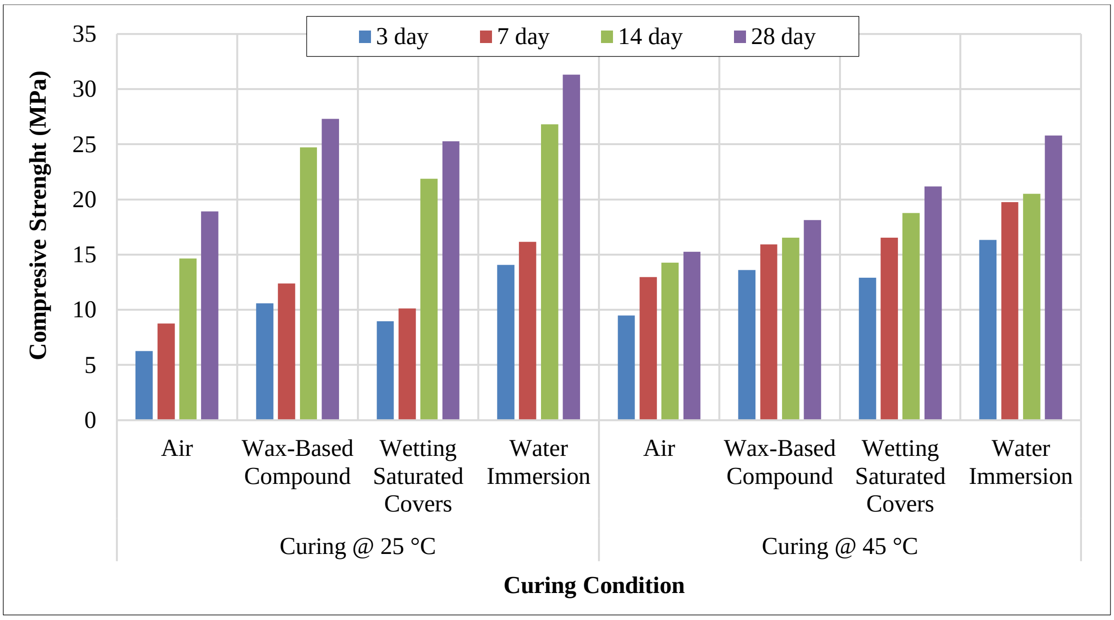


**Figure 3. Effect of curing methods and temperatures on compressive strength at different ages for OPC**

From Figures above, it is concluded that the increment in compressive strength of cement mortar is influenced by the method of curing and the environment conditions (how to keep the water for hydration process). When the water is available in sufficient amount the increase in the strength is clear. When the temperature of water increases, the hydration process is accelerated at the early ages as compared with the long term one, and the strength is developed with this acceleration, as shown in Figure 3 which presents the correlation between the compressive strength and the change of curing temperature at different curing time. Compressive strength increases when the curing temperature changes from 25 to 45° C in the early stage of curing by 16 and 22% for OPC at 3 and 7 days respectively (from 16.15 to 19.76 MPa), in the case of curing in the water immersion method, While the strengths at 14 and 28 days indicate an opposite manner; as the strength decreases when comparing the testing results at those ages by 23 and 17%,these results meet the observations by Cebeci, [21], Stated that concrete has higher values of compressive strength when the temperature of water curing is 37°C as compared with 17°C curing temperature, but this proportion decreases over time of curing till 28 days of curing. The rising in temperature of curing accelerate the reactions of hydration process and affect the strength of mortar at early age. the high temperatures causes a high rate of hydration at early ages leads to unknown uniform distribution for the following hydration products within the cement gel structure, It is attributed to the fact that insufficient time to redistribute the hydration products when the initial rate of hydration is high in the uniform matrix within the paste and away from the non-hydrated cement particles that have been excluded without being hydrated.

### 3.1.2. Cement Mortar Containing SRPC

Figure 4 shows the relation between the compressive strength of cement mortar specimens made with SRPC and curing methods at different ages.

The results indicate that the compressive strength of cement mortar by using immersion in water is still the leader and that the result obtained by using wax-based curing was 8 % greater than wet covering curing and 10% lower than the results obtained by using water Immersion curing for 28 days at 25° C curing condition. Development of compressive strength is affected significantly by the curing conditions; while compressive strength at early stages was higher for the samples cured in water Immersion conditions, the increase of compressive strength has been higher for samples cured at 25 °C within 28 days.

It's clear from Figure 4, when the temperature is raised to 45 °C, that compressive strength increases too, but with different ratios. These results indicate a significant increase in strength for cement mortar specimens that cured at 45 °C as compared with those cured at 25 °C. The rate of increase in compressive strength is about 29 and 33 % at 14 and 28 days respectively, when the temperature of curing is raised from 25 to 45° C for water immersion curing and 14 % for wax-based curing method at 28 days.

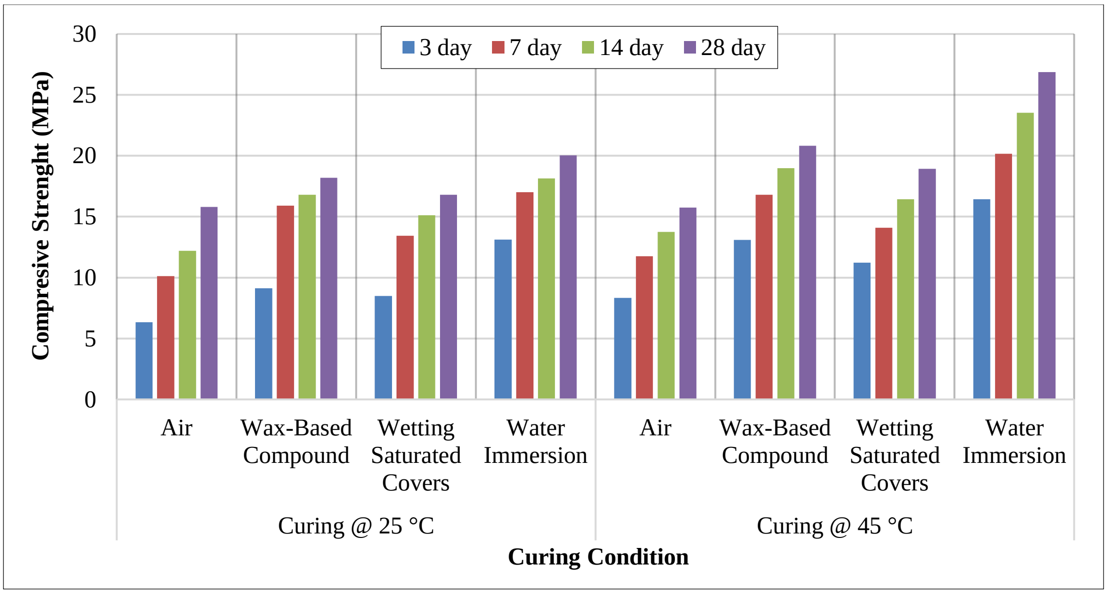


**Figure 4. Effect of curing methods and temperatures on compressive strength at different ages for SRPC**

## 3.2. Effect of Curing Methods on Flexural Strength

The testing results of flexural strength for the cement mortars are shown in Table 5 for different ages, various curing conditions and temperature.

**Table 5. Flexural strength results for cube specimens made from two types of cement at different ages and curing method**

| Cement Type | Temp. | Curing Method | Flexural Strength (MPa) | | | |
|---|---|---|---|---|---|---|
| | | | 3 Day | 7 Day | 14 Day | 28 Day |
| OPC | Curing @ 25 °C | Air | 4.04 | 6.4 | 6.96 | 7.5 |
| | | Wax-Based Compound | 6.76 | 8.3 | 9.3 | 10.98 |
| | | Wetting Saturated Covers | 5.06 | 7.9 | 8.04 | 9.12 |
| | | Water Immersion | 7.52 | 10.1 | 11.5 | 12.6 |
| | Curing @ 45 °C | Air | 3.28 | 6.02 | 6.7 | 6.98 |
| | | Wax-Based Compound | 4.2 | 6.46 | 7.02 | 7.58 |
| | | Wetting Saturated Covers | 3.76 | 6.2 | 6.84 | 7.18 |
| | | Water Immersion | 4.9 | 7.16 | 7.78 | 8.98 |
| SRPC | Curing @ 25 °C | Air | 3.04 | 4.6 | 5.74 | 5.88 |
| | | Wax-Based Compound | 5.6 | 6.9 | 7.04 | 7.72 |
| | | Wetting Saturated Covers | 4.48 | 5.74 | 6.44 | 6.86 |
| | | Water Immersion | 5.87 | 8.52 | 9.5 | 10.06 |
| | Curing @ 45 °C | Air | 2.87 | 4.2 | 4.42 | 4.74 |
| | | Wax-Based Compound | 3.4 | 4.58 | 5.46 | 6.58 |
| | | Wetting Saturated Covers | 3 | 4.26 | 4.88 | 5.12 |
| | | Water Immersion | 3.88 | 5.46 | 6.72 | 8.54 |

### 3.2.1. Cement Mortar Containing OPC

Figure 5 depicts the variation of flexural strength with ages for OPC cement mortar and curing methods. It has been observed that the rate of increase in flexural strength with curing time for the specimens that cured in water immersion gave higher values than another type of curing method at 25 °C curing temperature.

From Figure 5 it's noticed that flexural strength at 28 days for the specimens that cured by immersion in water and wax-based curing methods is higher than wet covering curing, while Air curing method has lowest flexural strength at all curing time and condition. The flexural strength of prisms cured by water immersion has been 12.8 and 27.6% greater than those cured by wax-based and wet covering curing at 28 days of curing and 25 °C curing condition.

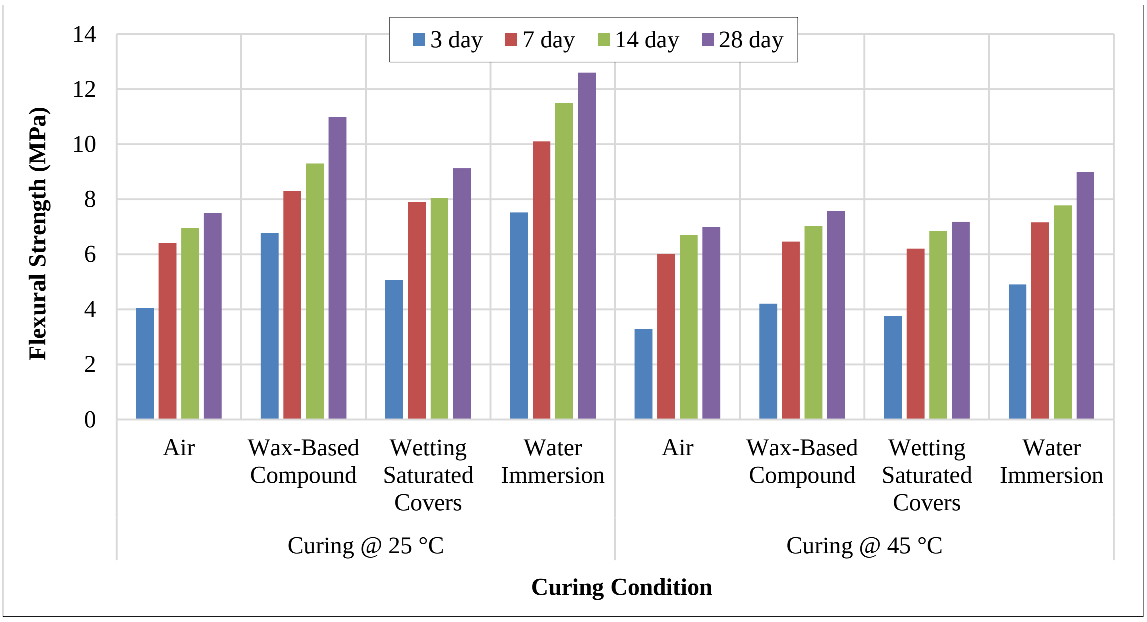


**Figure 5. Effect of curing methods and temperatures on flexural strength at different curing ages for OPC**

When we changed the curing temperature to 45 °C, it is observed that water immersion method maintain the same rate of increase in flexural strength with ages but the flexural strength of cement mortars at 45 °C have result less than obtained from 25 °C curing temperature for all ages and conditions.

The flexural strength at 28 days by using immersion in water and wax-based curing methods is normally higher than that obtained by wet covering and Air curing method which have close results as shown in the figure above. When tested the specimens after 28 days of curing it was found that the flexural strength of prisms cured by water immersion has been 22.9 and 40% greater than those cured by wax-based and wet covering curing methods.

Flexural strength decreased when the curing temperature changes from 25 to 45 °C by 29.1% at 7 days curing age. This deficiency continues to flexural strength with increasing the ages of curing.

### 3.2.2. Cement Mortar Containing SRPC

Figure 6 represents the variation of flexural strength with ages for SRPC cement mortar and curing methods. It has been observed that the rate of increasing in flexural strength with curing time for the sample that cured by water gave higher values than another type of curing method at standard curing temperature.

From Figure 6 it's noticed that flexural strength at 28 days for the specimens that cured by immersion in water and wax-based curing methods at 25°C curing condition is 10.06 and 7.72 MPa respectively, which is higher than wet covering curing, while Air curing method has lowest flexural strength at all curing time and condition. The flexural strength of prisms cured by water immersion has been 23.2 and 31.8% greater than those cured by wax-based and wet covering curing at 28 days of curing respectively.

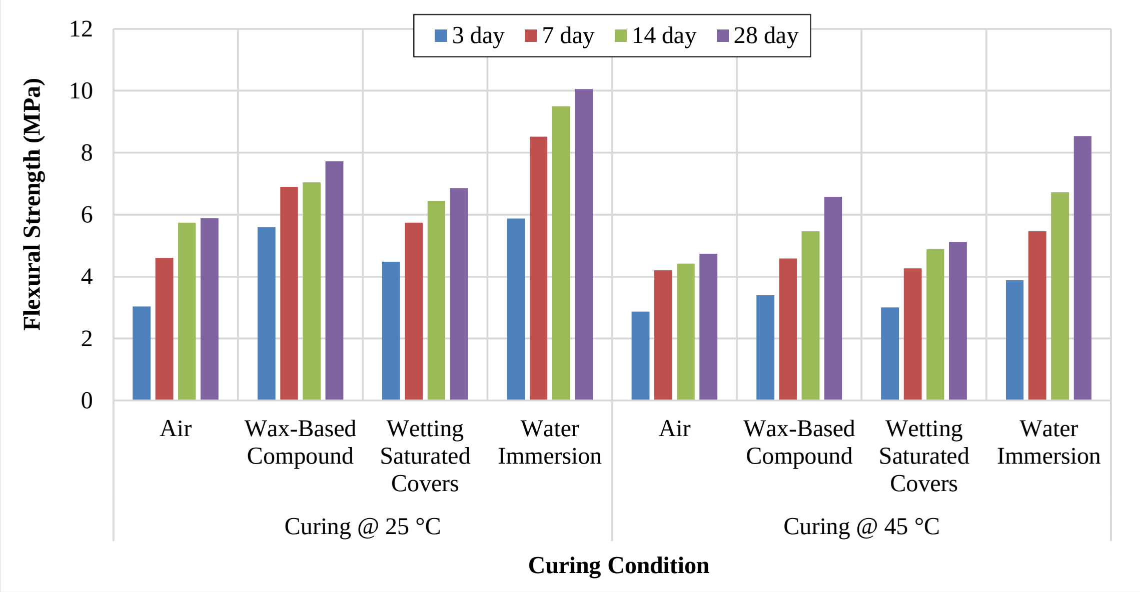


**Figure 6. Effect of curing methods and temperatures on flexural strength at different curing aged for SRPC.**

It's clear from the figure above, that curing temperature increases, the flexural strength decreased at different curing methods and ages. When we changed the curing temperature to 45 °C, it is observed that water immersion curing kept on higher flexural strength values rather than other types of curing method.

The flexural strength at 28 days by using immersion in water and wax-based methods are normally higher value than that obtained by wet covering and air curing methods. It is also observed that the sample cured by wet covering and air curing methods normally have close results for all ages. The 28 days flexural strength of prisms cured by water immersion has been 22.9 and 40% greater value than those cured by wax-based and wet covering curing methods.

When the temperature of curing is raised from 25 to 45 ºC, the rate of decreased in flexural strength is about 15.1 % at 28 days for immersion in water curing and 14.7 % for wax-based curing method.

## 3.3. Effect of Curing Methods on Density

The result of densities of cement mortar specimens at different ages is shown in table 6 for various curing conditions and temperatures.

**Table 6. Density of cement mortar specimens made with OPC or SRPC, and cured using the various method at 25 and 45 °C**

| Cement Type | Temp. | Curing Method | Density ($gm/cm^3$) | | | |
|---|---|---|---|---|---|---|
| | | | 3 Day | 7 Day | 14 Day | 28 Day |
| OPC | Curing @ 25 °C | Air | 2.01 | 2.08 | 2.14 | 2.18 |
| | | Wax-Based Compound | 2.23 | 2.26 | 2.29 | 2.35 |
| | | Wetting Saturated Covers | 2.2 | 2.22 | 2.25 | 2.26 |
| | | Water Immersion | 2.22 | 2.28 | 2.28 | 2.34 |
| | Curing @ 45 °C | Air | 2 | 2.16 | 2.19 | 2.2 |
| | | Wax-Based Compound | 2.04 | 2.19 | 2.23 | 2.27 |
| | | Wetting Saturated Covers | 2.16 | 2.18 | 2.2 | 2.23 |
| | | Water Immersion | 2.28 | 2.33 | 2.48 | 2.7 |
| SRPC | Curing @ 25 °C | Air | 2.0 | 2.18 | 2.21 | 2.23 |
| | | Wax-Based Compound | 2.21 | 2.28 | 2.3 | 2.32 |
| | | Wetting Saturated Covers | 2.2 | 2.26 | 2.27 | 2.27 |
| | | Water Immersion | 2.24 | 2.3 | 2.41 | 2.45 |
| | Curing @ 45 °C | Air | 2.06 | 2.07 | 2.09 | 2.13 |
| | | Wax-Based Compound | 2.18 | 2.19 | 2.22 | 2.26 |
| | | Wetting Saturated Covers | 2.17 | 2.17 | 2.19 | 2.2 |
| | | Water Immersion | 2.21 | 2.33 | 2.38 | 2.55 |

As shown in Figure 7 and 8, it could be seen that the pattern of increase in specimens density of cement mortar was similar to compressive strength, this leads to the fact that the density is directly correlated to the strength of cement mortar. This, therefore, suggests that an increase in both compressive strength and density of a mortar specimen is a function of the curing method. This increase in specimen density is due to the reduction of porosity of mortar by the hydration products which increase the weight of the sample with time for all ages. The average densities of the cement mortar cubes cured by water have greater values than those obtained by using the other curing methods.

Table 8, shows that the increment in the density of cement mortar is influenced by the method of curing and the condition method environment (how to keep the water for hydration process). When the water is available in sufficient amount the increase in the density is clear. When the temperature of water increases, the hydration process is accelerated and the density is developed with this acceleration.

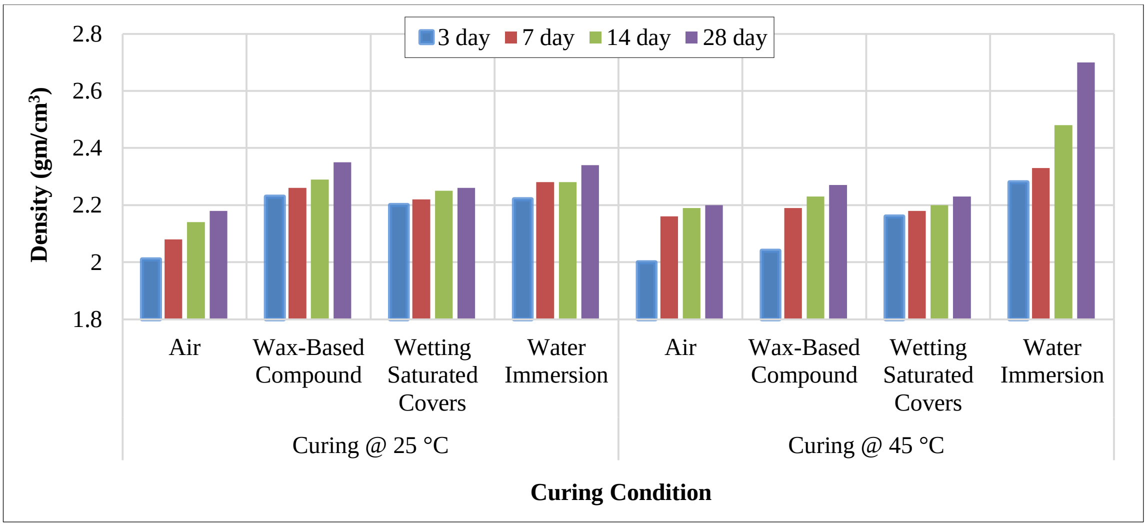


**Figure 7. Show the variation of cement mortar cube densities with curing methods and ages for OPC**

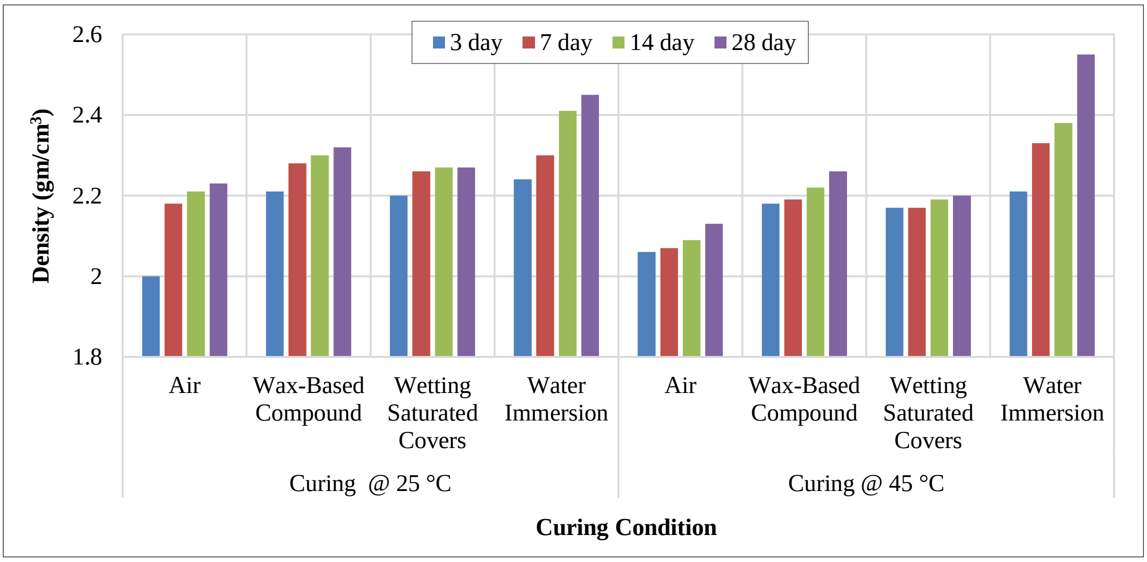


**Figure 8. Show the variation of cement mortar cube densities with curing methods and ages for SRPC**

## 4. Conclusions

Based on the test data and the evaluation of results obtained in this research, the following conclusions can be drawn:

- Water immersion and wax-based compound curing methods are the ones obtaining the higher values of cement mortar properties.
- Water immersion was the most effective method of curing because of fully hydration of cement paste and well-structured cement gel corresponding to minimal remaining capillary pores. This method produces specimens with the highest level in compressive strength and density, while Air curing produced the lowest test results.

- Wax-based and saturated wet covering curing methods achieved 75 to 85% efficiency of compressive strength as compared to water immersion curing method.
- Undesired strength was resulted from air curing, so that, this method should be avoided.
- At early ages and as the curing temperature increases, the compressive strength also increases for two types of cement mortars using OPC and SRPC cements.
- Cement mortar specimens cured at high temperature (45◦C) continuously for 28 days show different paths of developing the strength from 7 days to 28 days as compared with those specimens cured at 25◦C.
- For OPC mortars cured in water, the strength gained after 28 days at 45◦C is lower than that of 28 days at 25◦C by 19%, while, for SRPC mortars the strength is higher by 34%.
- The wax-based and wet cover curing methods used were effective and practical for maintaining the moisture content of mortars in hot weather regions.
- The average value of compressive strength for OPC mixtures by Immersion curing was observed to be 23% and 15% higher than Wet covers and wax-based curing methods at 28 days and at 25◦C, while, for increasing curing temperature from 25 °C to 45 °C, the results were increased by 22% and 42% higher than Wet covers curing and wax-based curing methods at 28 days.
- The average value of compressive strength for SRPC mixtures by Immersion curing was observed to be 19% and 10% higher than Wet covers and wax-based curing methods at 28 days and at 25◦C, while, for increasing curing temperature from 25 °C to 45 °C, the results were increased by 42% and 29% higher than Wet covers curing and wax-based curing methods at 28 days.

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## 6. Conflicts of Interest

The authors declare no conflict of interest.

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