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Research Article

EFFECT OF WATER CURING TEMPERATURE ON COMPRESSIVE STRENGTH DEVELOPMENT AND WATER ABSORPTION CAPACITY OF MORTAR MIXTURES

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ABSTRACT

In this study, the effect of different curing temperature processes on the 1, 3, 7 and 28-day compressive strength and 28-day water absorption ratios of mortar mixtures were investigated. All mortar mixtures were prepared according to ASTM C109. The water/cement ratio, sand/binder ratio and flow values of mortar mixture were kept constant as 0.485, 2.75 and 25±2 cm, respectively. Polycarboxylate ether-based high range water reducing admixture was used for providing desired flow value. All mortar mixtures were cured at fresh state in a curing room under the same conditions (Temperature of 20˚C and Relative humanity (RH) of 95%) during 24 hours from casting. Then, specimens were subjected to 6 different water-curing conditions. According to test results, the 3-day compressive strength of mixtures cured in water having a temperature of 40ºC was higher than that of mixtures cured at 20ºC in water. At early ages, the high curing temperature negatively affected the 7 and 28-day compressive strength of mixtures. Specimens cured in water at 20ºC and 40ºC had the highest and lowest 28-day compressive strengths, respectively. Different curing conditions had no significant effect on the 28-day water absorption ratios of mortar mixtures.
Keywords: Mortar mixture, curing conditions, water absorption, water curing temperature, compressive strength.

1. INTRODUCTION

As it is known, curing conditions affect the strength and durability of concrete seriously as well as sufficient workability, consistency and effective compacting. The permeability, which is the main parameter affecting concrete durability, is directly influenced by curing conditions. The water in concrete should be prevented from moving away in order to form the hydration reactions that occur in the process of gaining strength of concrete. For this purpose, concrete should be protected by performing surface irrigation or similar methods before gaining strength [1-3].

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Concrete properties such as strength behaviour, water permeability, permeability of Cl and CO_2, crack characteristic are influenced by curing regimes [4-9], curing time [4-6, 10-13], curing temperature [11, 13-17] and humidity [18-20]. Some related studies are summarized below:

The effect of accelerated curing on early age compressive and flexural strengths of mortars containing fly ash in different quantities was investigated by Yazici and Sezer [21]. Consequently it has been determined that strength loss, that occurred under standard curing conditions at early ages due to addition of fly ash, can be compensated by hot water curing. Bingol and Tohumcu [1] investigated the effect of different curing conditions (air curing, water curing and steam curing) on the compression strength of self-compacting concretes including silica fume and fly ash. According to the test results, mixture containing silica fume and cured in water showed the highest compressive strength.

In the other study, Haghighatnejad [22] searched the properties of recycled PVC aggregate concretes under different curing conditions. For this purpose, different curing regimes were applied including water curing, open-air curing, laboratory curing and mixed. According to the test results, different curing conditions affected the properties of both conventional concretes and concretes containing recycled PVC aggregate considerably.

In another research, the effect of different curing temperatures (20, 35 and 50˚C) on the mechanical properties and shrinkage behavior of high strength concrete containing steel and polypropylene fibers with different dosage and aspect ratios were studied by Bouziadi [23]. Test results indicated that the utilization of fiber improved the mechanical properties of concrete mixtures. Besides, increasing of curing temperature adversely affected the shrinkage of concrete mixtures.

In a similar study, the effect of curing temperatures on the mechanical properties and plastic shrinkage behaviour of plain and pozzolanic cement was analysed [14]. In this context, curing temperatures were changed as 25, 32, 38 and 45˚C. In pozzolanic cement systems, 30% of fly ash, 10% of very fine fly ash, 7% of silica fume, 70% of blast furnace slag and 20% of natural pozzolan were used. Test results indicated that the highest and lowest plastic shrinkage values were observed in the mixtures cured at the temperatures of 25 and 38˚C, respectively. Besides, the optimum temperature was determined as 32˚C for both conventional concrete and concrete containing silica fume, while the optimum temperature was determined as 38˚C for concrete containing other pozzolans in terms of strength properties and ultrasonic pulse velocity.

In the other empirical work, Hong and et al [24] investigated the effects of curing time and curing temperatures on the strength properties of polysulfide polymer concrete. In this context, a number of laboratory experiments were carried out to investigate the bond, flexural and compressive strengths of the specimens. The inspection curing temperature and curing time ranges were from -10 to 60˚C and 3h to 28 days (672 h), respectively. According to the attained results, the curing temperature beyond 20˚C adversely affected the compressive, flexural and bond strengths of mixtures.

Zheng and et al [25] analysed the effect of seawater curing on the permeability resistance and mechanical properties of green artificial reef concrete. For this purpose, three different curing regimes such as standard curing, freshwater curing (20±2˚C), and seawater curing (20±2˚C) were employed. As per obtained results, the splitting tensile and compressive strengths of green artificial reef concrete were slightly affected by the three different curing systems. Besides, the permeability of green artificial reef concrete increased in the seawater curing regimes.

Meloleepszyj [26] in an experimental research observed that the strengths of mortars containing 5% and 10% silica fume were affected by the curing conditions. Based on found results, due to applying air curing on samples the compressive strength decreased as 40%.

Özcan and et al [27] in a laboratory work evaluated the effects of various curing conditions (wet and dry curing) and silica fume on the compressive strength of mortar. For this aim, the ordinary Portland cement was substituted with silica fume into different ratios by weight (0%, 10%, 15%, 20% and 40%). The sand/binder ratio was kept constant as 2.75 and the water/binder ratios were used as 0.25, 0.30, 0.40, 0.50 and 0.60. In order to measure mixtures' strengths, half of prepared mortar specimens were kept i n the curing room under 20±2˚C temperature with a relative humidity of 65±5%, and the remainder of them were kept at the same temperature in water until the day of the experiment (1, 3, 7 28 days). As per found records, the compressive strength of the specimens kept in the dry curing room with 20˚C ambient temperature and 65±5% relative humidity decreased about 50% than that of the specimens kept in the wet curing conditions.

Toutanji and et al. [28] assessed the influence of curing techniques on permeability, permeable voids and compressive strength of concrete mixtures containing silica fume under three different curing regimes (moist, steam and air curing). In this context, 10%, 15%, 20%, and 30% weight of cement were replaced with silica fume and the range of aggregate/binder ratios was from 1.0 to 3.8. As per experimental reports, the mechanical properties of specimens under steam curing improved, but the samples kept in the air curing conditions showed negative results than the moist curing state. In addition, due to improvement of mechanical properties of mixtures under steam curing condition, the permeability and permeable void volume of concrete with silica fume decreased.

In a laboratory research, the effects of two different curing methods (dry and wet curing) on compressive strength of concrete mixtures containing silica fume were studied by Atis and et al [29]. For this investigation, the concrete cubic specimens with four different W/C ratios (0.3, 0.4, 0.5, 0.6) and three different cement dosages (350, 400, 450 kg/m^3) were produced. Moreover, 10%, 15% and 20% of cement were replaced with silica fume partially. All concrete specimens were removed from the mold after 24 hours then the half of them were kept in a cabinet at 20±2˚C with 65% relative humidity (RH), and the rest of cubic specimens were cured in a cabin at 20±2˚C with 100% RH until the test day (28 days). According to obtained results, the compressive strength of specimens containing silica fume under curing condition (65% RH) was affected adversely compare to that of specimens containing only portland cement.

An empirical investigation was conducted by Ramezanianpour [30] to study the performance of concrete incorporating with slag, fly ash, and silica fume under four varied curing methods. In this work, the water-binder ratio of all samples was determined as 0.5 but only for the high volume fly ash concrete specimens it was kept constant as 0.35. In order to investigate the performance of concrete mixtures, the specimens were exposed to the four different curing conditions such as moist curing, room temperature curing, two days at moist then keeping them at room temperature curing, and curing at 38˚C with 65% relative humidity (RH). The results of performed tests showed that the reduction of the moist-curing period decreased the strengths in low extent, increased porosity and more permeable concrete. Besides the resistance to chloride ions increased due to the incorporation of binder material (slag, silica fume, high volumes of fly ash) in the mixtures.

Dayanidhy and Balasundaram, [31] studied the influences of curing techniques on durability properties of self-compacting concrete containing metakaolin. For this aim, the concrete specimens were cured with six various curing methods, namely wet covering, immersion, seawater, hot water, ice and polyethylene film. The outcomes of experimental works showed that immersion curing techniques had the least effect against acid and sulphate attacks.

Briefly, different curing methods can affect the properties of concrete positively or negatively. There are many studies about the effect of curing conditions on the mechanical and durability performance of concrete. However, it is understood from the literature, some uncertainties about the subject still continue because of many parameters such as different curing regimes, heterogeneous of cementitious systems, selection of concrete components in a wide range, development of concrete technology and various binding systems. The issue of the investigation of the effect of curing conditions on the properties of cementitious systems is one of the important issues that need to be studied.

This investigation is a part of an extensive study that examines the effect of water curing temperature change on some hardened properties of mortar mixture. For this aim, prepared mortar mixtures were cured in a curing room under same conditions (having a temperature of 20˚C and RH of 95%) during 24 hours from casting. Then, the mortar specimens were removed from the mold and were cured in water under different temperature conditions until the testing day.

Seven different curing processes with curing temperatures of 20 and 40˚C were applied. The effect of curing processes on the 1, 3, 7 and 28-day compressive strength and 28-day water absorption capacity of mortar mixtures were investigated.

2. EXPERIMENTAL PROGRAM

2.1. Materials

In this study, CEMI 42.5R type cement in accordance with EN 197-1 standard was used as a binder. The physical, mechanical properties and chemical composition of the cement provided by the manufacturer are given in Table 1.

Table 1. Chemical composition, mechanical and physical properties of cement

Item	(%)	Physical properties		
SiO_2	18.86	Specific gravity		3.15
Al_2O_3	5.71	**Mechanical properties**		
Fe_2O_3	3.09	Compressive strength (MPa)	1-day	14.7
CaO	62.70		2-day	26.80
MgO	1.16		7-day	49.80
SO_3	2.39		28-day	58.5
Na_2O+0.658 K_2O	0.92	**Fineness**		
Cl^-	0.01	Blaine specific surface (cm^2/g)		3530
Insoluble residual	0.32	Residual on 0.045 mm sieve (%)		7.6
Loss on ignition	3.20			
Free CaO	1.26			

In the production of mortar mixtures, a type of crushed limestone aggregate having a maximum size of 4 mm was used. The specific gravity and water absorption values of the aggregate given in Table 2 were obtained conforming to EN 1097-6 standard. Sieve analysis of aggregates given in Table 3 was performed according to EN 206-1 standard.

Table 2. Specific gravity and water absorption capacity of limestone aggregate

Aggregate		Bulk SSD specific gravity	Absorption capacity (%)
Type	Size (mm)		
Limestone	0–4	2.68	1

Table 3. Particle size distributions of aggregates

Sieve size (mm)	Percent passing (%) 0-4 mm
31,5	100
16	100
8	100
4	100
2	77,5
1	49,3
0,5	32
0,25	12,9
0,125	2,5

A type of polycarboxylate-ether based high range water reducing admixture (HRWR) was used in order to achieve the desired target flow. Some properties of the chemical admixture provided by the manufacturer are shown in Table 4.

Table 4. Properties of high range water reducing admixture (HRWR)

Type	Density (gr/cm^3)	Solid content (%)	pH value	Chloride content (%)	Alkali content (Na_2O) (%)
Polycarboxylate-ether based high range water reducing admixture	1,097	36,35	3,82	<0,1	<10

2.2 Mix proportions

Mortar mixtures were produced in accordance with ASTM C109 standard. In this regard, water/cement ratio and sand/binder ratio were determined as 0.485 and 2.75, respectively. The amounts of materials used in the production of mortar mixtures are shown in Table 5. The flow values of all mixtures were kept constant as 25±2 cm. As shown in Table 5, HRWR was used up to 0.5wt% of the cement in order to provide the desired flow value.

Table 5. Mix proportions of all mortar mixtures

Cement	Water	Aggregate (0-4 mm)	HRWRA*	Flow value
500 g	242,5 g	1375 g	2,5 g	240 mm

* High range water-reducing admixture

2.3. Curing conditions and testing procedures

The prepared mortar mixtures were cured in a curing room under same conditions (20˚C and 95% RH) during 24 hours after casting. Then they were cured in water under different temperature conditions until the testing day. The specimens cured in the same conditions were removed from the molds and subjected to 6 different water-curing conditions. The mortar specimens are designated regarding the curing conditions. For example, specimens cured in water with a temperature of 20°C for 27 days were designated as C-27(20°C). The samples which were cured in water with a temperature of 40°C for 3 days and then cured in water at 20°C for 24 days were designated as C-3(40°C)-24(20°C). The designations of mortar mixtures are summarized in Table 6.

Table 6. Sample codes and cure conditions

Mixture	Stages	Curing Time (day)	Temperature (ºC)
C-27(20°C)	1. Stage (in mold)	1	20
	2. Stage	27	20
C-3(20°C)-24(40°C)	1. Stage (in mold)	1	20
	2. Stage	3	20
	3. Stage	24	40
C-3(40°C)-24(20°C)	1. Stage (in mold)	1	20
	2. Stage	3	40
	3. Stage	24	20
C-7(20°C)-20(40°C)	1. Stage (in mold)	1	20
	2. Stage	7	20
	3. Stage	20	40
C-7(40°C)-20(20°C)	1. Stage (in mold)	1	20
	2. Stage	7	40
	3. Stage	20	20
C-27(40°C)	1. Stage (in mold)	1	20
	2. Stage	27	40

Details of the curing conditions are shown in Fig. 1. As it is emphasized earlier, all mortar mixtures were cured at the same conditions (20 ºC, 95% RH) during 24 hours from casting.

C-27(20°C): The mortar specimens were cured in lime-saturated water at 20°C until the day of the experiment.

C-3(20°C)-24(40°C): The mortar specimens cured at 20°C for 3 days and then at 40°C in the lime-saturated water until the day of the experiment.

C-3(40°C)-24(20°C): The mortar specimens cured at 40°C for 3 days and then at 20°C in the lime-saturated water until the day of the experiment.

C-7(20°C)-20(40°C): The mortar specimens cured at 20°C for 7 days and then at 40°C in the lime-saturated water until the day of the experiment.

C-7(40°C)-20(20°C): The mortar specimens cured at 40°C for 7 days and then at 20°C in the lime-saturated water until the day of the experiment.

C-27(40°C): The mortar specimens cured in lime-saturated water at 40°C until the day of the experiment.

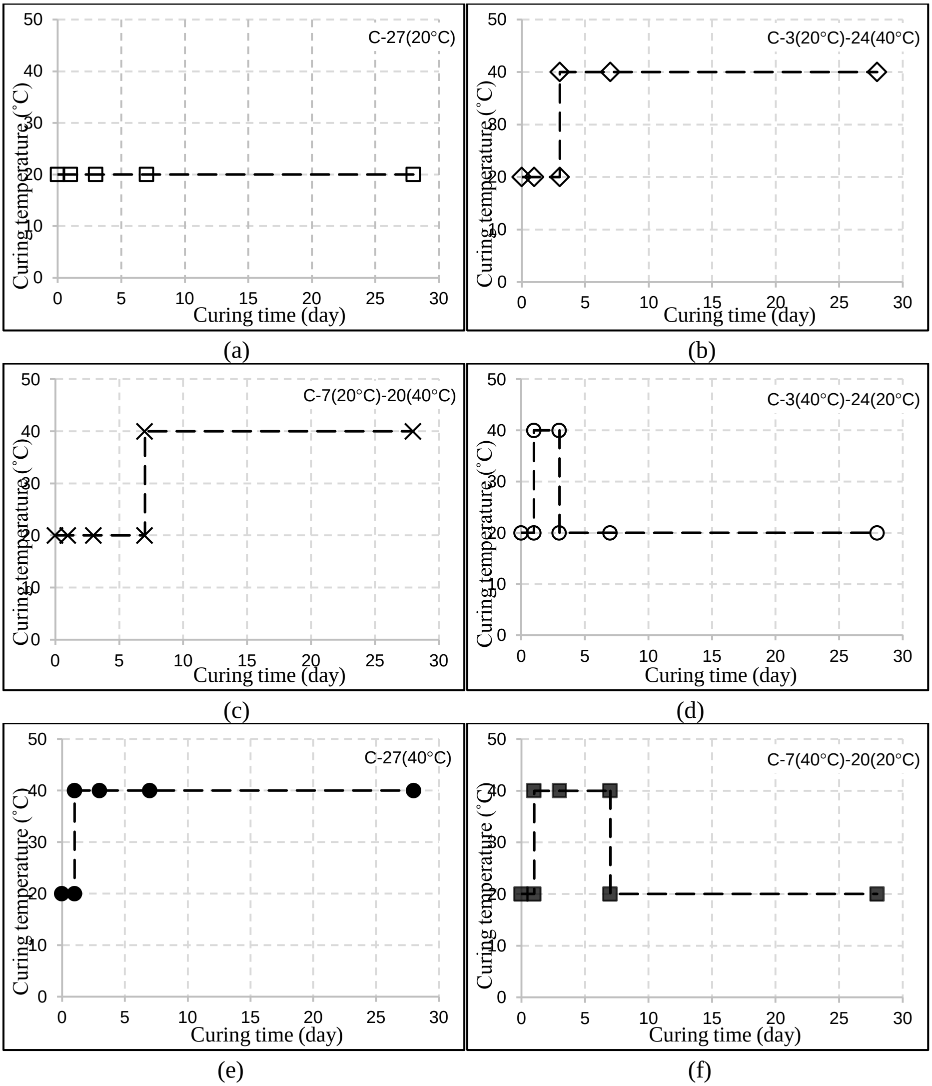

Figure 1. Curing periods of mortar mixtures

The flow tests of the mortar mixtures were carried out in accordance with ASTM C1437 standard. The 1, 3, 7, 28-day compressive strengths and 28-day water absorption ratios were determined on 50 mm cube specimens according to ASTM C109 and EN 1097-6 standards, respectively.

3. RESULTS AND DISCUSSION

The 1, 3, 7 and 28-day compressive strength results of mortar mixtures are shown in Fig. 2. The relative compressive strength values of the mixtures compared to the 1-day strength are given in Fig. 3 and 4. In the mentioned figures, the 1-day compressive strength of mortar mixture was shown as C. As previously explained, all mortar mixtures were cured under the same conditions (20ºC, 95% RH) during 24 hours from casting. The average of the 1-day compressive strength of all mixtures is shown in Fig. 2. As it can be seen from the results, irrespective of different curing temperature, the compressive strength of all mortar mixtures increased by elapsing time. The compressive strength of specimens cured at 40ºC in water for 3 days was 5% higher than that of specimens cured at 20ºC for 3 days. The compressive strength of specimens cured in water at 20ºC for 7 days was 8% higher than that of specimens cured in water at 40ºC for 7 days. Compared to the mortar specimens cured in water having temperature of 40ºC for 3 days then cured in water having temperature of 20ºC for 4 days, the specimens cured at 20ºC for 3 days then cured at 40ºC for 4 days showed 9% higher compressive strength. The strength of the C-7(20ºC) mixture cured at 20ºC for 7 days was obtained 15% higher than that of C-3(40ºC)-4(20º) mixture cured at 40ºC for 3 days and at 20ºC for 4 days.

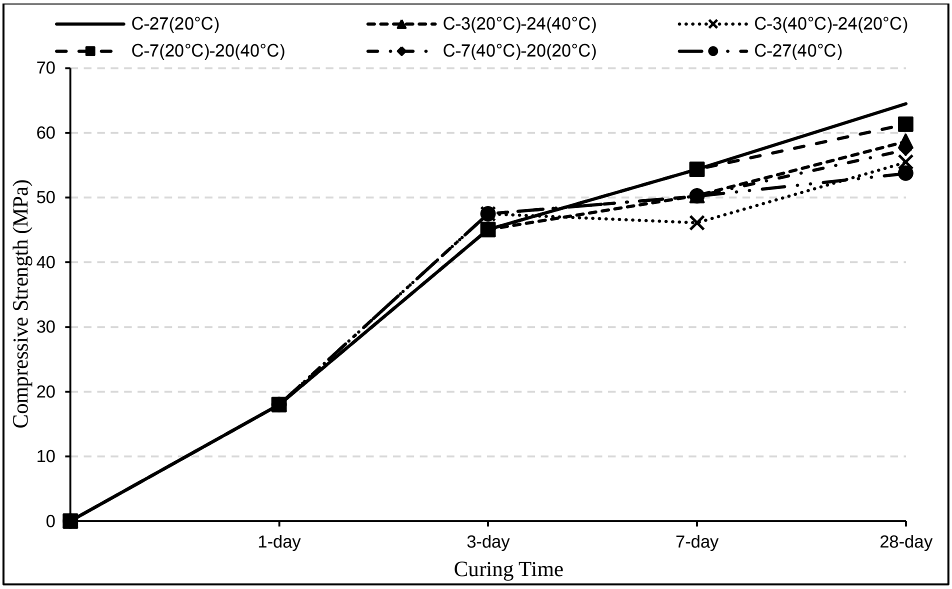

Figure 2. 1, 3 and 7-day compressive strengths of mortar mixtures

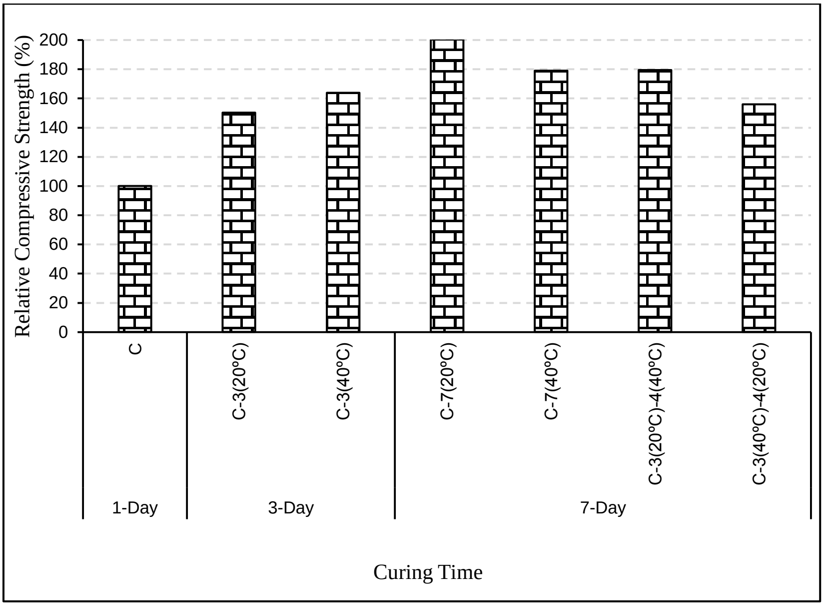

Figure 3. 1, 3 and 7-day relative compressive strengths of mortar mixtures

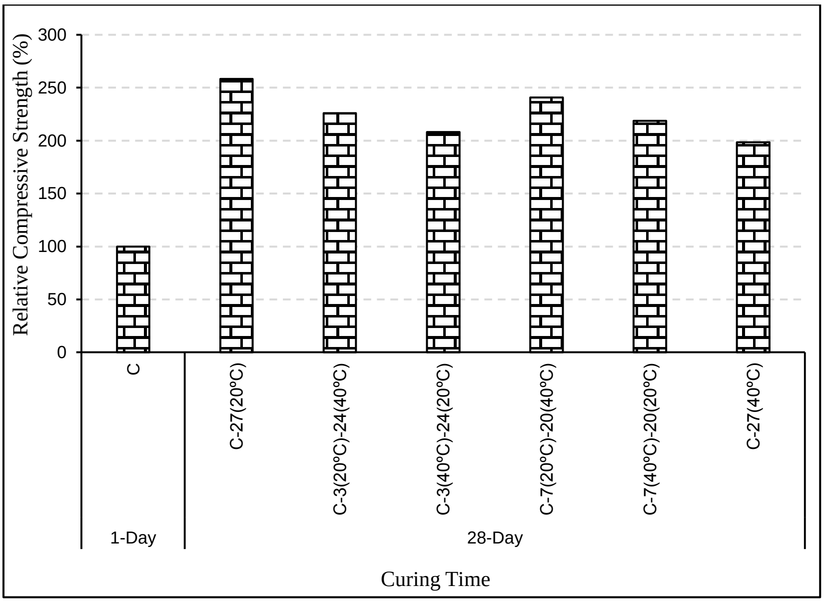

Figure 4. 28-day relative compressive strengths of mortar mixtures

The maximum compressive strength value was observed for the C-28(20ºC) mortar mixture cured under standard conditions (20ºC) during 28 days compared to the other mixtures cured at different water curing temperatures. The lowest 28-day compressive strength was observed for the

C-28(40ºC) mixture cured in water at 40°C during 28 days. As it can be seen from the test results, the 3-day compressive strength of mortar mixture slightly increased by applying water curing having a temperature of 40ºC. However, beyond 3 days, the compressive strength of mortar mixtures was adversely affected by applying water curing having a temperature of 40ºC. As it is known, curing temperature is one of the significant factors affecting the development of concrete strength. It also plays an essential role in the hydration of cement and microstructure formation [32]. Higher curing temperatures at early ages cause to increase the hydration rate of cementitious systems [33, 34]. Thus, the structure of the hydrated cement paste starts to form at an early age and leads to strength development at early age [35, 36]. According to Wang and Liu [33], the high curing temperature at early ages accelerates the hydration of cement clinker phases. The strength increases due to accelerating the formation of the C-S-H phase. However, the high rate of hydration at early ages brings about the formation of non-uniform heterogeneous gel products [35-40]. Due to the formation of non-homogeneous gel products, a more porous structure is formed. Thus, strength is adversely affected in later ages. Furthermore, the gel products cover the surface of the unhydrated cement particle after the cement components start to hydration process very rapidly. Thus, the risk of access to unhydrated cement particles of mixing water increases and the development of strength is affected negatively [41].

The 28-day water absorption capacity of mortar mixtures cured in water having different temperatures for 28 days are shown in Fig. 5. The water absorption ratios of mixtures cured at different conditions were determined as approximately 6%. As it can be seen from the results, the change in curing temperature has no significant effect on the 28-day water absorption capacity of mortar mixtures.

The relationship between 28-day compressive strength and water absorption capacity of the mortar mixtures are shown in Fig. 6. It can be seen from Fig. 6 that there is a weak polynomial relationship between the compressive strength and the water absorption ratio of the mortar mixtures.

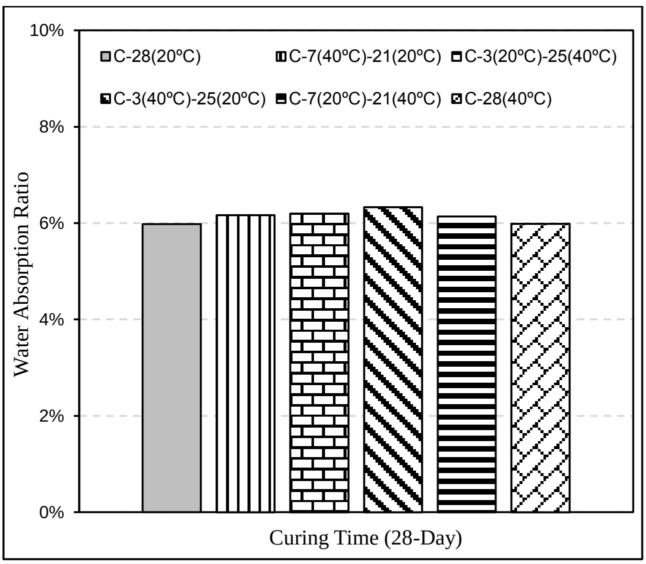

Figure 5. The 28-day water absorption capacity of mortar mixtures

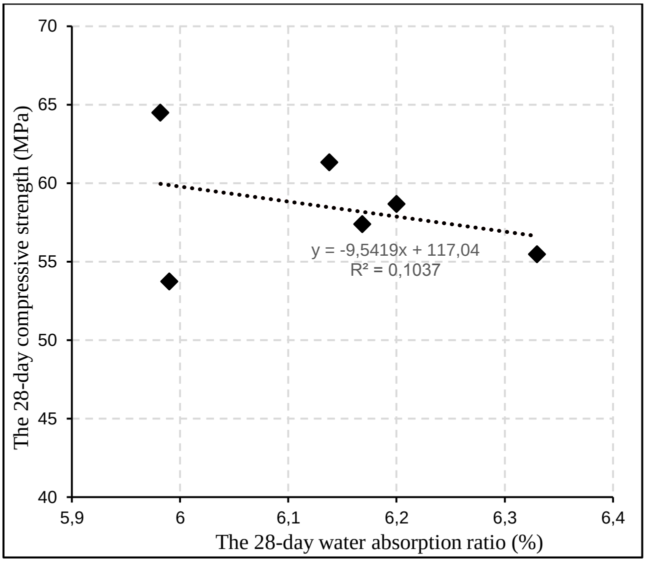

Figure 6. Relationship between the 28-day compressive strength and water absorption ratio of mortar mixtures

4. CONCLUSIONS

The following significant findings were obtained regarding materials and experiments in this study:

- The 3-day compressive strength of mixtures cured in water having temperature of 40ºC was higher than that of mixtures cured in water having temperature of 20ºC. However, the high curing temperature at early ages affected the compressive strengths of 7 and 28 days adversely. This negative effect is thought to be caused by the formation of an inhomogeneous and pore structure due to the higher curing temperature at early age.
- The highest and lowest 28-day compressive strengths were determined on specimens cured in 20ºC and 40ºC water for 27 days, respectively.
- The changing of curing temperature had no remarkable effect on the 28-day water adsorption capacity of the mixtures.

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