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Research Article

Evaluation of Compressive and Tensile Strength of Self-Curing Concrete by Adding Crushed Bricks as Additive Material

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Curing is an essential stage in the production of concrete because it controls cement hydration and strength evolution. One of the methods of curing is the internal or self-curing which can be achieved by using materials of specific characteristics inside concrete to provide moisture from within the concrete as opposed to outside of it. This water should not affect the water-cement ratio. Lightweight coarse or fine aggregate or using absorbent polymer particles with an ability to keep water inside the concrete mixture can be used for this purpose. This study presents the use of crushed brick as a curing agent and evaluate its effects on the compressive and tensile strengths of concrete at different ages. Four mixes were used: M0, M10, M20, and M30. All the aggregates in mix M0 are natural gravel, while mixes M10, M20, and M30 contain 10%, 20%, and 30% crushed bricks, respectively, as replacement of coarse aggregate. The tests results showed that using crushed brick as a self-curing agent gave compressive strength up to 87.8% and splitting tensile strength up to 169% compared to water-cured concrete.

1. Introduction and Literature Review

The objectives of curing are to maintain moisture in concrete and to preserve a favorable concrete temperature for a period of time [1]. Curing directly affects the hydration of cement, and it has an impact on the development of all properties of concrete [2]. In order to sustain the hydration of cement, the relative humidity should be maintained at a minimum of 80% inside the concrete [3]. The importance of curing arises from the fact that hydration of cement paste can only take place in water-filled capillaries [4]. Concrete with poor curing will at best lead to dusty and friable surfaces and at worst to possible failures in service [5].

According to ACI (308–213) R-13 [6], prewetting the lightweight aggregate is an important procedure for improving the quality of the finished concrete. Internally cured concrete includes absorptive materials in the mix that supply moisture to the internal of concrete. This procedure adds moisture without affecting the water-cement ratio. Self-curing concrete can be defined as concrete in which the cement hydration occurs because of obtaining additional internal water that is not part of mixing water. Self-curing is allowed for curing from the inside to outside by the means of saturated lightweight aggregate that works as internal storage [7, 8].

Several researchers proposed the use of saturated lightweight aggregates to supply internal curing inside concrete [9, 10, 11]. The external curing process cannot be achieved properly in many situations, commonly due to unavailability of modern equipment and unskilled workers.

Clay brick is very common in Iraq due to the relative low cost and availability. Crushed clay brick can be considered as lightweight aggregate with relatively high absorption capacity; therefore, it has the potential to be used as the internal curing medium in concrete mixtures. Internal curing using crushed bricks is environmentally friendly as it reduces water needed for external curing and utilizes brick waste [10]. The presence of porous aggregate in concrete for self-curing (internal curing) may reduce the compressive strength [11].

Al-Saffar et al. [12] concluded that internal curing is more effective at later ages on splitting tensile strength and flexural strength than on compressive strength. Also, they emphasized that internal curing concrete can produce denser hydrated cement paste than those mixes without inner supply of water. The production of ettringite is useful for developing the microstructure of hydrated cement paste.

Iffat et al. [13] pointed out that internally cured concrete can perform better than reference samples with crushed bricks. Therefore, crushed bricks can be used as a cost-effective internal curing material to produce durable concrete.

Nassar et al. [14] used lightweight aggregate with 0, 10, 20, and 30% replacement of normal weight aggregate and crushed stone as fine aggregate with 100% replacement of sand. They concluded that the compressive, flexural, and split tensile strengths and the static modulus of elasticity of concrete mixtures reduced when the percent replacement of normal weight aggregate with lightweight one increased.

Balapour et al. [15] evaluated the potential use of spherical porous reactive aggregate, which is produced from waste coal bottom ash, as lightweight aggregate for internal curing of concrete. This type of aggregate showed acceptable capability regarding the desorption behavior for concrete internal curing, and it can be used as lightweight aggregate for self-curing concrete.

Li [16] explored the potential for self-curing of saturated recycled fine aggregate (RFA) in mortar. The study stated that RFA with finer particle size and higher water absorption capacity can produce greater reduction in autogenous shrinkages, especially at the first three days, which could be due to RFA porosity. Self-curing with RFA was observed obviously in a mixture with high aggregate content.

Rani [17] used fire brick to produce self-curing concrete. The brick was taken from inner lining of kiln meant for firing as partial replacement of sand. The best quantity of crushed fire brick was found to be 30% of sand weight based on the seven days compression test. Also, he stated that the water-cured concrete mixes produced better results compared to self-cured mixes. The compressive strength of water-cured concrete showed higher values compared to self-cured concrete. The decrease in compressive strength for 7 days, 14 days, and 28 days was 35.8%, 23.18%, and 26.02%, respectively.

Rashwan et al. [18] used crushed over burnt clay bricks with replacements ratios of 20%, 50%, and 100% from coarse aggregate. They found that the value of 20% saturated crushed over burnt bricks represent the optimum dose as a self-curing agent in concrete for conventional water curing, air curing regime, and chemical curing. They noticed an increase in compressive strength of about 1.7% with ratio of 20% replacement of conventional and no curing conditions. The increase of indirect tensile strength of self-cured mixtures with 20% replacement was 2.1% for self-cured concrete.

The scope of the current study is to assess the compressive and splitting tensile strengths of concrete at different ages (3, 7, 14, and 28 days) using local crushed bricks as a self-curing agent with several replacement ratios of coarse aggregates (0, 10, 20, and 30%). These percentages were selected based on literature where the replacement ratio should be kept as low as possible in order not to highly decrease the compressive strength [11].

2. Experimental Program

2.1. Materials and Mix Proportions. Ordinary Portland cement (type 1) that conforms to ASTM C150 [19], fine aggregate (natural sand), coarse aggregate (gravel with maximum aggregate size 20 mm and specific gravity 2.63) that conforms to ASTM C33 [20], crushed brick (maximum aggregate size 20 mm and specific gravity 2.24) as shown in Figure 1, and water have been used through the testing program for producing concrete. Aggregates in all mixes were used in a state of saturated surface dry to utilize the low specific gravity (high porosity) as compared to natural aggregate by filling their pores with water in order to get the self-curing mechanism.

Four concrete mixes were used: M0, M10, M20, and M30. All mixes have the same cement, sand, and water contents. The difference between them is the percentage of the added crushed brick as replacement from gravel weight. Mix M0 only contains gravel without crushed brick, M10 contains 10% crushed brick, M20 contains 20% crushed brick, and M30 contains 30% crushed brick. The proportions of concrete batches are given in Table 1.

2.2. Experimental Procedure. The mixing procedures have been conducted according to ASTM C 192 [21]. The slump test results which were performed according to ASTM C [22] for all mixes ranged from 140 mm to 170 mm and did not show visual signs of segregation during the casting of concrete in the moulds. Mix M0 was cured in water (external curing) for 28 days, while the other mixes (M10, M20, and M30) were cured in air (internal or self-curing) for 28 days. For each mix, 12 cubes of size 100 mm × 100 mm ×100 mm and 8 cylinders of size 100 mm × 200 mm were cast. Three cubes and two cylinders were tested for compressive strength and splitting tensile strength, respectively, for each age according to BS EN 12390–3 [23] and ASTM C496 [24]. The tests were conducted at 3, 7, 14, and 28 days.

3. Results and Discussion

The results of compressive strength and splitting tensile strength for all mixes and at different ages are given in Table 2.

3.1. Effect of Crushed Bricks Ratio. Figure 2 shows the effect of crushed brick ratio on compressive strength. Figure 3 shows cube sample during the compressive strength test. It is clearly shown from Figure 2 that the compressive strengths for all ages decrease with the increase in crushed brick ratio. The compressive strengths of self-cured mixes M10, M20, and M30 compared to the reference water-cured mix M0 are 77.8%, 66.4%, and 53.3%, respectively, at 3 days; 74.7%, 66%, and 60.7%, respectively, at 7 days; 67.9%, 56.9%, and 55.4%, respectively, at 14 days; and 87.6%, 77%, and 70.4%, respectively, at 28 days. The results confirm that using

Figure 1: Crushed bricks sample.

Table 1: Mix proportions of concrete mixes.

Mixture description	M0	M10	M20	M30
Cement (C), kg/m^3	400	400	400	400
Sand, kg/m^3	600	600	600	600
Gravel, kg/m^3	1200	1080	960	840
Crushed brick, kg/m^3	0	120	240	360
Water (W), kg/m^3	200	200	200	200
W/C	0.5	0.5	0.5	0.5

Table 2: Results of compressive strength and splitting tensile strength.

Mixes	Compressive strength, MPa				Splitting tensile strength, MPa			
	3 days	7 days	14 days	28 days	3 days	7 days	14 days	28 days
M0	12.2	15	20.03	26.7	0.5	0.71	1.2	1.75
M10	9.5	11.2	13.6	23.4	0.5	0.93	1.4	1.8
M20	8.1	9.9	11.4	20.6	0.4	0.97	1.5	1.97
M30	6.5	9.1	11.1	18.8	0.6	1.2	1.6	2.03

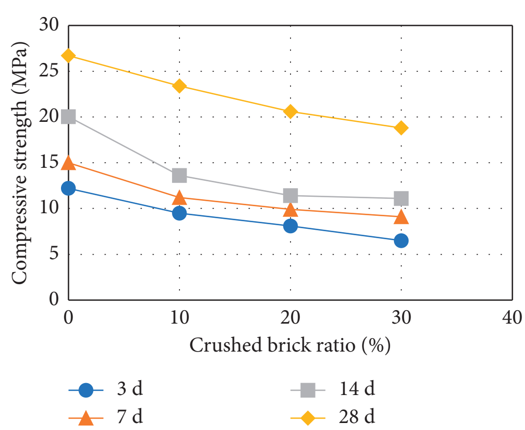

Figure 2: Effect of crushed brick ratio on compressive strength of concrete.

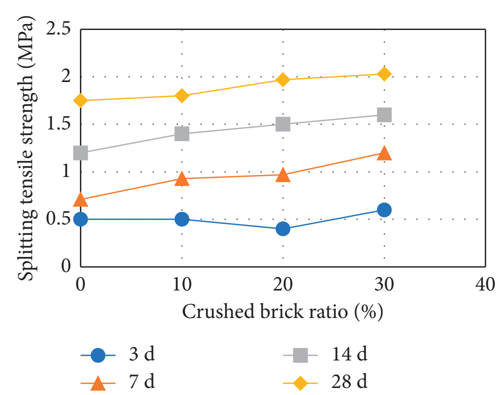

Figure 3: Effect of crushed brick ratio on splitting tensile strength of concrete.

crushed brick as a self-curing agent with ratios of 10%, 20%, and 30% of coarse aggregate gives compressive strength at 28 days between 70.4% (for M30) and 87.6% (for M10) as compared to the conventional water-cured mix without crushed bricks. The reduction in compressive strength for self-curing mixes is expected because they contain crushed bricks whose strength is lower than that of natural gravel. As a result, cured bricks may be broken under load leading to earlier failure than reference mix.

The results of splitting tensile strength are shown in Figure 4. Figure 5 shows the cylinder sample during the splitting tensile strength test. It is clear from Figure 3 that there is an increase in splitting tensile strength with the increase of crushed brick ratio. The splitting tensile strengths of self-cured mixes M10, M20, and M30 compared to the

Figure 4: Compressive strength test.

Figure 5: Splitting tensile strength test.

reference water-cured mix M0 are 100%, 80%, and 120%, respectively, at 3 days; 130%, 136%, and 169%, respectively, at 7 days; 116.7%, 125%, and 133.3%, respectively, at 14 days; and 102.9%, 112.6%, and 116%, respectively, at 28 days. This may be attributed to the water in crushed bricks pores which plays a role in the internal curing process to continue the cement hydration and to improve the tensile and bond strengths of cement paste whose contribution is more effective in developing the concrete tensile strength than the aggregate.

3.2. Effect of Age. The effect of age on compressive strength is shown in Figure 6. The figure shows that the compressive

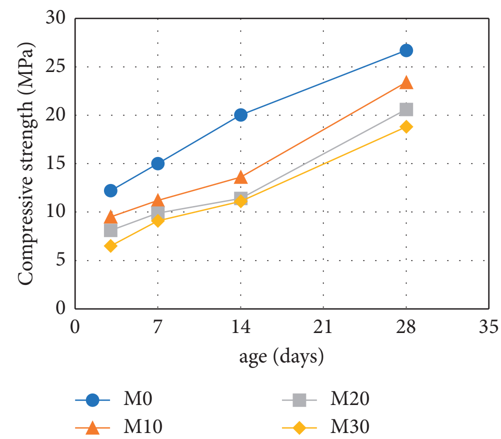

Figure 6: Effect of age on compressive strength of concrete.

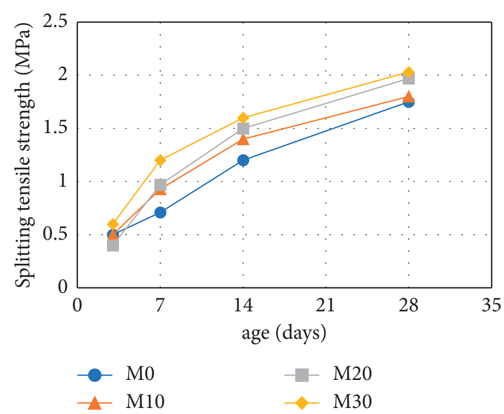

Figure 7: Effect of crushed brick ratio on splitting tensile strength of concrete.

strength of mixes increases with the increase in age. The compressive strength of water-cured mix M0 is the highest for all ages, followed by mixes M10, M20, and M30. The compressive strengths at age 3, 7, and 14 days compared to the 28-day compressive strength are 45.7%, 56.2%, and 75%, respectively, for water-cured mix M0; 40.6%, 47.9%, and 58%, respectively, for self-cured mix M10; 39.3%, 48.1%, and 55.3%, respectively, for self-cured mix M20; and 34.6%, 48.4%, and 59%, respectively, for self-cured mix M30. These results show that although the evolution of strength in self-curing mixes slower than reference mix, the cement hydration process continues consuming the water in the crushed brick pores.

The effect of age on splitting tensile strength is shown in Figure 7. It is evident that the splitting tensile strength of all mixes increases with the increase in age. The splitting tensile strength at ages 3, 7, and 14 days compared to the 28 days splitting tensile strength are 28.6%, 40.6%, and 68.6%, respectively, for water-cured mix M0; 27.8%, 51.7%, and 77.8%, respectively, for self-cured mix M10; 20.3%, 49.2%, and 76.1%, respectively, for self-cured mix M20; and 29.6%, 59.1%, and 78.8%, respectively, for self-cured mix M30. This may be also attributed to the pores of crushed bricks which contain water needed for internal curing for the concrete and for allowing a continuous hydration which resulted in an improvement in splitting tensile strength as shown in Figures 4 and 7.

4. Conclusions

The experimental results lead to the following conclusions:

(i) The compressive strength of self-curing concretes with 10, 20, and 30% replacement ratios of crushed bricks, compared to the reference concrete of water curing, is between 53.3% and 87.6%. The lower values of compressive strength for self-curing concrete mixes are a result of the existence of crushed brick whose strength is lower than that of natural gravel and thus may be fractured under compression load and leading to early failure.

(ii) As crushed brick ratio increases, the splitting tensile strength increases. The splitting tensile strength of self-curing concrete are between 80% and 169% as compared to water curing concrete.

(iii) The compressive strengths of water curing concretes are the highest values for all ages followed by M10, M20, and M30 concrete mixes. The ratios of the compressive strengths at ages 3, 7, and 14 days to that at 28 days vary from 34.6% to 75%.

(iv) Comparing to the splitting tensile strength at 28 days, the 3, 7, and 14 days tensile strengths ranged from 20.3% to 78.8%. This may be attributed to the continuous hydration resulted from the internal curing provided by the water pores of the crushed bricks.

Data Availability

The data used to support this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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