Influence of Internal Curing on the Mechanical Properties of Normal Strength Concrete

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Abstract—

The current study investigated the influence of internal curing on the mechanical properties of normal concrete produced at the Islamic University of Gaza (IUG) laboratories. Due to high absorption capacity of the local broken pottery fragments, crushed pottery material was utilized in this study as the internal water storage source. The specific gravity and the absorption capacity of the crushed pottery (CP) sieves were identified to ensure the suitability of such material. The current study investigated the partial replacement of 0%, 10%, 15%, 20% and 25% of fine aggregates with CP material. Slump tests were carried out for the CP samples to obtain the effect of various contents on the workability of the mixes. The CP specimens were also prepared to obtain the mechanical properties, including the compressive strength and flexural strength. The compressive strength of the samples was obtained at ages of 7, 14 and 28 days. The optimum CP content was identified and applied to study the flexural strength. The results of the experiments showed that the use of the locally available crushed pottery as an internal curing material was effective in curing the concrete samples. The partial replacement of the natural fine aggregates with various contents of CP was also positive for the slump values. Further, the application of CP material was successful in improving the early compressive strength and flexural strength. A slight improvement in the 28-days strength results was revealed with the increasing content of CP. The slump and strength results indicated that 20% partial replacement of fine aggregates with CP material was the optimum.

Index Terms— Internal curing, crushed pottery, compressive strength, flexural strength.

I INTRODUCTION

Concrete curing is the term given to the procedures used for promoting the hydration of the cement, and consists of a control of temperature and of moisture movement from and into the concrete [1]. Curing allows continuous hydration of cement and consequently continuous gain of the strength. Proper curing of concrete structures is significant to meet the concrete performance and durability requirements. In conventional curing this is achieved by external curing applied after mixing, placing and finishing. Curing of concrete maintains satisfactory moisture content in concrete during its early stages in order to develop the desired properties. However, effective curing is not always practically achieved in many cases. Therefore, the need to develop more effective curing agents attracted several researchers [2-5]

Self-curing or internal curing (IC) is a technique that can be used to provide additional internal moisture inside concrete in order to enhance hydration of cement and reduce self-desiccation. Internal curing is a mean of maintaining moisture or supplying an internal water source for concrete that promotes more cement hydration. Self-curing concrete is a special concrete that would overcome insufficient curing due to human negligence. Further, such concrete would help in case of scarcity of water in arid areas, inaccessibility of structures in difficult terrains and in areas where the presence of fluorides in water will badly affect the characteristics of concrete [6-8].

Among the methods available for internal curing are the use of saturated porous lightweight aggregate (LWA), use of polyethylene glycol which reduces the evaporation of water from the surface of concrete and helps in water retention. Further, application of superabsorbent polymers is utilized as an internal curing method, which could absorb and retain extremely large amounts of a liquid relative to their own mass [8, 9].

Bentur, et al. [10] studied concrete with replacement of 25% of the normal weight aggregates with saturated lightweight aggregate. They indicated that this concrete exhibited no autogenous shrinkage, whereas the normal-weight concrete with the same matrix exhibited large shrinkage. The results showed that such concrete was very effective in eliminating the autogenous shrinkage and restrained stresses of the normal-weight concrete.

Kamal, et al. [11]**,** in their first stage of the study, investigated the effect of internal curing agents on the main properties of normal-strength and high-strength self-compacted concrete. The internal curing agents included chemical curing agents and Light Expanded Clay Aggregates “LECA” as internal reservoirs. Results indicated that curing agents reduced the water evaporation from concrete, and increased the water retention capacity with sufficient hardened concrete properties.

Shen, et al. [12] utilized internal curing (IC) with up to 50 % prewetted lightweight aggregates (LWAs) to enhance the early-age behavior of high performance concrete. This was included temperature, shrinkage, creep deformation and stress for low cracking potential. They indicated that internally cured concrete with prewetted clay LWAs is more robust for construction at early ages.

Wu, et al. [13] investigated the replacement of normal aggregates by several proportions of waste recycled brick aggregate (RBA) as an internal curing material in concrete. The results demonstrate that RBA has a great potential for internal curing purpose in recycled aggregate concrete.

Kevern and Nowasell [14] obtained the effect of replacing small fraction of normal fine aggregates in concrete with prewetted lightweight aggregates. This study concluded that the results of the concrete strength, degree of hydration, shrinkage, and freeze–thaw testing showed substantial improvements over the control mixture. Therefore, the study strongly recommended applying internal curing as a routine curing for concrete.

Lee, et al. [15] investigated the potential of utilizing recycled aggregates (RA) as an internal curing agent for an alkali activated slag (AAS) system compared with using artificial lightweight aggregates. They indicated that RA could reduce the autogenous shrinkage of an AAS system without a decrease in compressive strength. Further, the addition of RA did not increase degree of hydration for AAS mortar. This resulted from the dilution effect of the alkali activator, which was caused by the additional water supplied from internal curing materials.

In high performance concrete, high self-desiccation and high temperature rise occur due to the low water-to-cement would increase the cracking potential of concrete at early age. Therefore, Shen, et al. [16] studied experimentally the effect of using pre-wetted lightweight aggregates (LWAs) on the tensile creep and cracking potential of high performance concrete at early age under adiabatic condition. They showed that using pre-wetted LWAs to internally cure concrete reduced the autogenous shrinkage, tensile creep/shrinkage as compared with the corresponding values of normal concrete.

Mousa, et al. [17] investigated the mechanical properties of concrete having replaced pre-soaked lightweight aggregate with several ratios of sand (0%, 10%, 15% and 20%). They indicated that the optimum ratio of pre-soaked lightweight aggregate was 15%, which showed improved mechanical properties. Mousa, et al. [18] indicated also that replacing 20% of pre-soaked lightweight aggregate with sand was effective for improving permeability and mass loss, but adversely affects the sorptivity and volumetric water absorption of the tested concrete samples.

The aim of the current study is to investigate the influence of internal curing on the mechanical properties of normal concrete produced at IUG laboratories. Crushed pottery material was utilized as an internal water storage source. Several contents of crushed pottery were added to concrete mixes in partial replacement of fine aggregates to obtain its effect on the mechanical properties.

II Martials and Experimental Program.

A. Material Properties

Crushed pottery (CP) was utilized as an internal source of water to perform the internal curing process. The crushed pottery introduced to the mix as a partial replacement of fine aggregates in several percent. The specific gravity and the absorption capacity of the crushed pottery were tested in accordance to ASTM D6473 [19] and ASTM C642 [20], respectively.

The crushed pottery (CP) was obtained from several factories that deal with such damaged material, as shown in Figure 1. The CP was crushed and dried at 105 C^0 for 24 hours and the absorption capacities of various sizes of CP are presented in Table 1.

Figure 1. Crushed pottery (CP)

The absorption values of CP was compared with light weight aggregates (LWA) used by Dayalan and Buellah [21]. The absorption of the 2.36 to 0.6mm CP sizes ranges between 10.82% to 12.2%, respectively, which compares well with that of LWA (10.03%) indicated by Dayalan and Buellah [21]. Therefore, an equal combination of CP sizes of 2.36, 1.18 and 0.6 mm was made for the internal curing process. The experiments showed that the specific gravity of the CP is 2.52.

Table 1. Absorption results of crushed pottery (CP)

CP particle size (mm)	Absorption capacity, % (ASTM D6473-15)
2.36	11.1
1.18	12.2
0.6	10.82
0.425	7.23
0.3	6.14
0.15	4.61
0.075	4.46

Ordinary Portland Cement II AM 42.5 N was used in this study; the specific gravity of the cement was taken as 3.15. The fineness of the cement particles was 4200 cm^2/g; the initial and final setting time were 1.5 and 6.5 hours, respectively, based on ASTM C191 [22].

The maximum size of the coarse aggregate (CA) was 20 mm. The average specific gravity and absorption of the coarse aggregates were 2.61 and 2.1 %, respectively. The grading of coarse aggregates is shown in Table 2.

Sand was applied as fine aggregate (FA) and the specific gravity and absorption of the fine aggregates obtained in accordance to ASTM D6473 and ASTM C642 were 2.41 and 0.9%, respectively. The grading of the fine aggregate is presented in Table 3.

Table 2. Grading for coarse aggregate

Sieve opening, mm	Passing, %
19.00	100
12.50	90
9.50	45
4.75	0

Table 3. Grading for fine aggregate

Sieve opening	Percent passing
No. 16	100
No. 30	76
No. 50	10
No. 100	4

B. Experimental Program

The current study investigated partial replacement of fine aggregates with four contents of the CP. These CP contents included 0%, 10%, 15%, 20% and 25%. The mix design of the concrete samples was carried out based on ACI 211 [23]. The results of the mix design proportions is included in Table 4.

Table 4. Mix proportions for $1m^3$ concrete

proportions	CP samples				
	0%	10%	15%	20%	25%
w/c ratio	0.43				
Cement, kg	442				
CA, kg	1073				
FA, kg	795	716	676	636	597
CP, kg	0	80	120	159	199

The 150 mm-cube samples were kept in a dry place with room temperature of 25 °C. These samples were maintained in this place until the day of testing.

The fracture of various CP cube samples revealed well distribution of CP particles in the concrete matrix, as shown in Figure 2. This well distrubtuion ensures that the internal curing process covers the complete concrete matrix.

Slump tests were carried out for the CP samples according to ASTM C143 [24] to obtain the effect of various CP contents on the workability of the mixes. The CP specimens were tested to obtain the mechanical properties; namely the compressive strength and flexural strength according to ASTM C39 [25] and ASTM C78 [26]. The compressive strength of the samples was obtained at ages of 7, 14 and 28 days for w/c of 0.43. Afterwards, the optimum CP content mix was applied to study the flexural strength. Finally, the long-term compressive strength was also studied at age of 90 days.

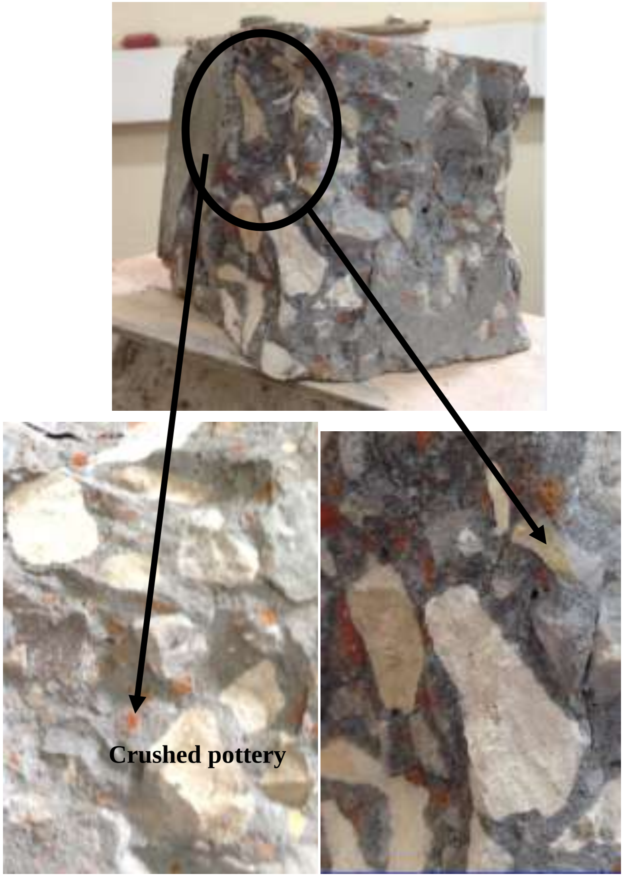

Figure 2. Well distribution of Crushed pottery particles

III. Results and Analysis.

It was observed that the CP samples showed wet appearance on the surfaces at the age of 3 days and at room temperature. This indicates that the CP particles started releasing its internal water to the mix and hence the internal curing continues well, as shown in Figure 3. This wet appearance remained for the first 7 days. Afterwards, this wet appearance disappeared gradually. This finding was not observed in the 0% CP samples.

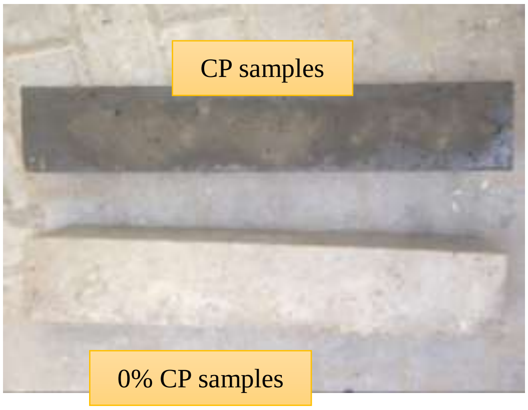

Figure 3. Wet appreance on the CP samples compared with 0% CP samples at 3 days age and room temperature.

A. Slump

Slump values of 3.3, 3.5, 3.7, 3.8 and 4.1cm for 0%, 10%, 15%, 20% and 25% CP samples are presented in Figure 4. The results indicated that the partial replacement of the natural fine aggregates (sands) with various contents of CP was positive for the slump values. This would be attributed to a small portion of the internal water stored in CP particles is added to the free water of the mix, which in turn improves the workability. Such behavior of workability improvement needs more investigation and study.

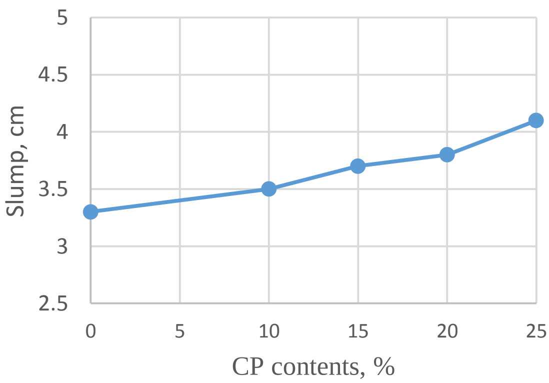

Figure 4. Slump values for CP samples

B. Compressive Strength

The compressive strengths of the CP samples were obtained at ages of 7, 14, 28 and 90 days. Figures 5 to 8 present the compressive strength of the CP samples at various ages.

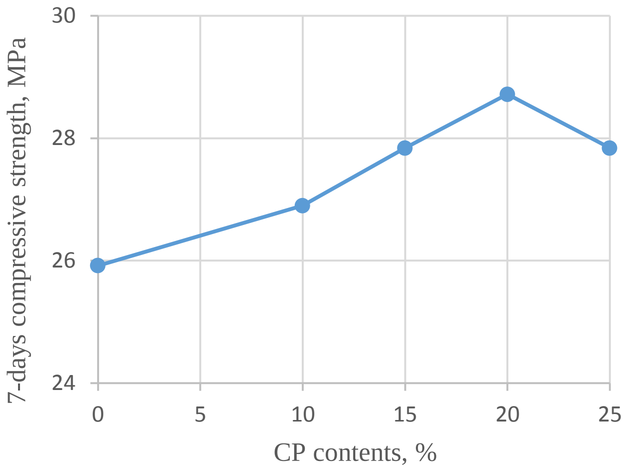

Figure 5. Compressive strength for CP samples at 7- days

Figure five shows that increasing the CP content up to 20 % of the sand content resulted in improving the 7 days compressive strength (early strength) up to 7.5%. Afterwards, any further increase in CP content (25%) showed a reduction in the early strength improvement.

The 14 days strength of the CP samples, as shown in Figure 6, showed a similar improvement to that of the 7 days strength values. As the CP content increased to 20% replacement of sand the 14 days strength values improved by 6.7%. A reduction in the 14 days strength was indicated beyond the 20% CP content (i.e. 25%).

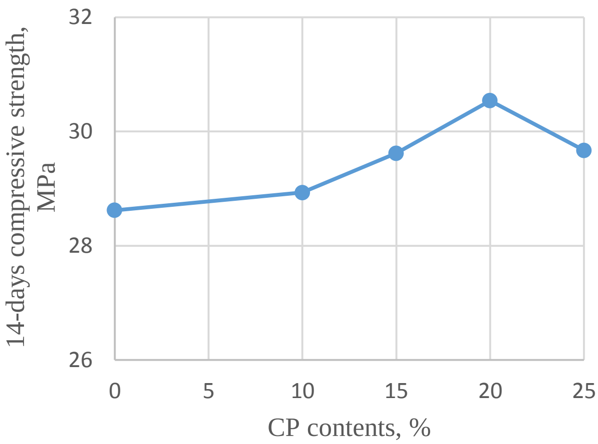

Figure 6. Compressive strength for CP samples at 14 days

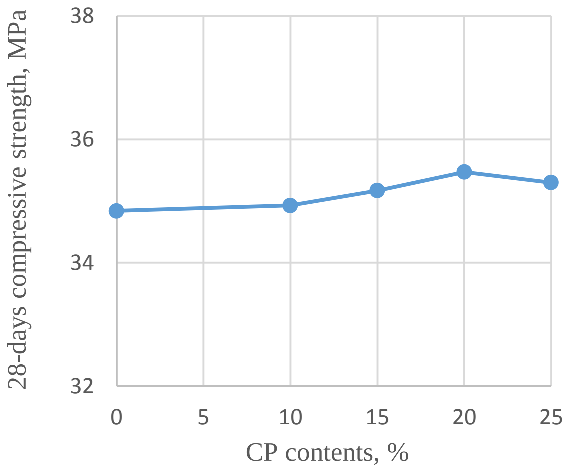

Figure 7. Compressive strength for CP samples at 28 days

A slight improvement in the 28 days strength results was revealed as the CP contents increased, as shown in Figure 7. No significant improvement in the 28 days compressive strength beyond 20% CP content of sand replacement.

The compressive strength results indicated that the use of CP as an internal curing material was effective in curing the concrete samples. This finding was confirmed by the fact that higher strength values are obtained in this study. This behavior can be attributed to the continuing process of cement hydration due to the availability of more internal relative humidity that is stored inside the CP particles. This continuation of cement hydration process ensures lower voids and pores, and greater bond between cement paste and aggregate particles, as mentioned by several researches [27-29].

Further, the use of CP material for internal curing was successful in improving the early strength of the samples. It can be concluded that the optimum partial replacement of fine aggregates by CP content is 20%. This optimum CP content was applied for the subsequent stages of the experimental program. This result agrees very well with the optimum content of light weight aggregates applied by [17] and [16], who obtained an optimum content between 15 to 20 %.

The long-term effect of the internal curing of CP material on the compressive strength was also investigated using the optimum CP content (20%). The 0% and 20% CP content samples were kept in a dry place for 90 days in a room temperature of 25 °C. Compressive strength at 7, 28 and 90 days of the 0% and 20% CP content samples are presented in Figure 8.

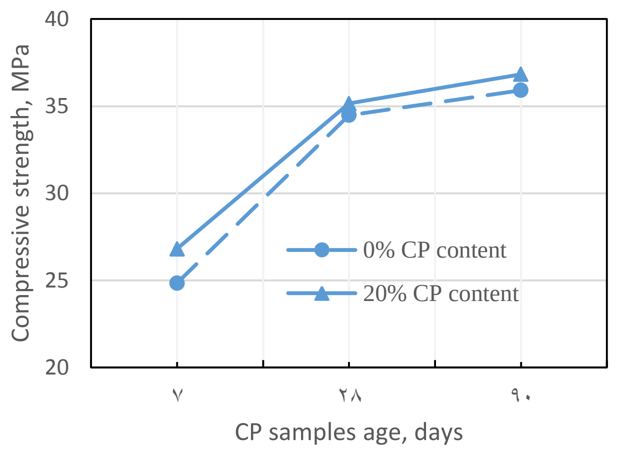

Figure 8. Compressive strength of 0% and 20% CP samples at 7, 28 and 90 days

The long-term compressive strength results presented in Figure 8 showed that the improvement in strength continues beyond the 28-days strength almost with the same rate as compared with the 0% CP samples. This finding can also be attributed to the continuation of the cement hydration for longer times.

C. Flexural Strength

Flexural strength of the 0% and 20% CP samples at 7 and 28 days are indicated in Figure 9. The results revealed that there was an increase of 19.5% in the 28 days flexural strength of the 20% CP content sample as compared with that of the 0% CP content sample. This finding can be referred to the obtained improvement of the compressive strength, which was in turn reflected positively on the flexural strength.

V CONCLUSIONS

The current study investigated the influence of internal curing on the mechanical properties of normal concrete. Crushed pottery material was utilized as the internal water storage source. Having performed the experimental program and analyzed the results, the following conculsions were achieved:

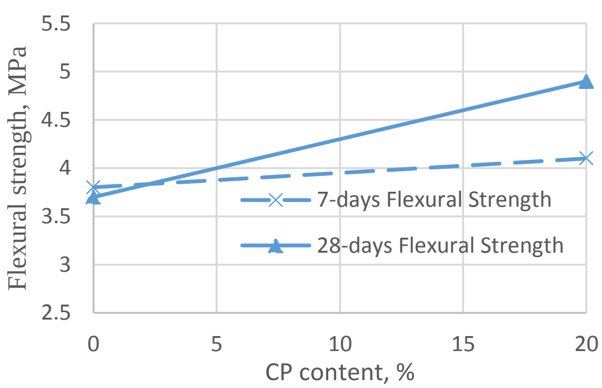

Figure 9. Flexural strength of 0% and 20% CP samples at 7 and 28 days.

1- The use of the locally available crushed pottery as an internal curing material was effective in curing the concrete samples.

2- The partial replacement of the natural fine aggregates (sands) with various contents of CP was positive for the slump values. The workability of the CP samples was higher than that of the control samples (0% CP).

3- The use of CP material for internal curing was successful in improving the early strength of the concrete samples. There was an increase of 7.5% and 6.7% in the 7 days and 14-days strength for the 20% CP samples, respectively, as compared with the control samples.

4- A slight improvement in the 28 days strength results were revealed as the CP contents increased. No significant improvement was obtained at the 28 days compressive strength beyond the 20% CP content of sand replacement.

5- The slump and strength results indicated that the optimum partial replacement of fine aggregates by CP content as an internal curing material is 20%.

6- The long-term compressive strength results showed that the improvement in strength continues after the 28 days strength with the same rate as compared with the 0% CP samples.

7- The results indicated that there was an increase of 19.5% in the 28 days flexural strength of the 20% CP content sample as compared with that of the 0% CP content sample.

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