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Effect of absorption of limestone aggregates on strength and slump loss of concrete

Abdulrahman M. Alhozaimy *

Center of Excellence for Concrete Research and Testing, Civil Engineering Department, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia

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ABSTRACT

Slump loss of concrete is very important in construction practice particularly with ready-mixed concrete. It is believed that slump loss occurs due to reduction of mixing water caused by aggregate absorption, evaporation, and cement hydration. In this study, the effect of absorption of limestone aggregates on the effective w/c ratio and on the strength and slump loss of concrete was investigated. It was found that the absorption of dry aggregates in all concrete mixes considered in this study occurred mainly in the first 15 min after the start of mixing and diminished substantially thereafter. The rate of slump loss of concrete was almost identical for mixes with dry and wet aggregates, even when setting time was extended. The results indicated that limestone aggregates used in this study with an absorption capacity of 1.3–1.9% by weight can absorb about 75% of their absorption capacity when mixed in concrete. The remaining 25% will add to the free water, thus increasing the effective w/c ratio. This phenomenon was demonstrated by the increased initial slump and decreased compressive strength of mixes with dry aggregates compared to those with wet aggregates.

1. Introduction

Loss of workability of concrete with time, often referred to as slump loss, is very important in construction practice, particularly with ready-mixed concrete where long haul times and delays on site are common. Slump loss occurs due to the effects of cement hydration, evaporation, and absorption of water in the case of dry aggregate; its rate is influenced mainly by cement characteristics, cement content, water/cement ratio, ambient and concrete temperature, initial slump and presence of admixture [1–4].

The coarse and fine aggregates generally occupy 70–80% of the concrete volume and have an important influence on its fresh and hardened properties. Most normal-weight aggregates (fine and coarse) have absorption capacities in the range of 1–2% by weight of aggregate [5]. The water absorption rate of typical limestone aggregates is high when the aggregates are first wetted but rapidly decreases with time [6]. Slump loss, affected by the moisture condition of aggregates, is expected to be greater with dry aggregates because of the absorption of water by aggregates [7,8]. The use of aggregates in dry condition is common in arid regions. CIRIA [9] guide to reinforced concrete construction in the Arabian Peninsula cites that dry aggregates can absorb 10–20% of the total added water which will considerably reduce workability from the time of discharge from the mixer to the time of placing.

Literature pertaining to the influence of absorption of aggregates on the slump loss of concrete is limited. Neville [8] asserts that the absorption of water by dry aggregates results in some loss of workability with time, but beyond about 15 min the loss becomes small. He attributed this phenomenon to dry aggregates becoming quickly coated with cement paste particularly in rich mixes; thus preventing further ingress of water necessary for saturation. Accordingly, he recommended adding a reduced quantity of water to be absorbed in the initial 10–30 min instead of the total quantity of water based on a 24 h absorption period. Shetty [10] also opposed the use of 24 h of absorption arguing that the amount of absorption of aggregates should be based on a time interval equal to the final set of cement paste. ASTM C 192 states that the amount of water absorbed by the aggregates before the concrete sets may be assumed to be 80% of the difference between the 24 h absorption of the aggregates, determined by test methods C 127 or C 128, and the amount of water in the pores of the aggregates in their room-dry state, determined by test method C 566. However, this standard is restricted to the case of low absorption aggregates where the water absorption is less than 1.0% [11].

In the hot, dry environments such as in the central region of Saudi Arabia, aggregates are often in a dry state. Increased rate of slump loss and the corresponding tendency to add water at the jobsite is considered one of the potential problems for fresh concrete in hot weather. The objective of this study is to investigate the effect of absorption of local limestone aggregate on the effective w/c ratio and on the strength and slump loss of concrete.

2. Experimental program

In this study, the effects of two aggregate conditions (air-dry and wet) on the slump loss and the compressive strength of

* Tel.: +966 14677013; fax: +966 14677008.
E-mail address: alhozimy@ksu.edu.sa

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concrete with and without a retarding admixture were investigated. Different initial slumps were considered. ASTM C494 Type D water reducing and retarding admixture was used to investigate the effect of extended setting time of concrete on the absorption of aggregates. The experimental program is summarized in Table 1.

3. Materials and mix proportions

Materials used in this study are those typically used by ready-mixed concrete in the region. A brief description of all materials is given below.

The cement used was type I manufactured by local cement factory; it complies with the standard specification requirement of ASTM C 150. Crushed limestone coarse aggregates were obtained from local quarries as a blend of maximum sizes of 20 and 10 mm per the gradation limit of ASTM C 33. Manufactured-sand fine aggregates were obtained from crushed limestone with a gradation per ASTM C 33 requirements. Coarse and fine aggregates used in this study were stored in containers in the laboratory environment. The specific gravity and absorption capacity of the aggregates were determined in accordance with ASTM C 127 and C 128. The specific gravity of the 20 and 10 mm coarse aggregates and crushed sand were 2.56, 2.55, and 2.57, respectively. Absorption of coarse and fine aggregates carried out at different times of immersion in water is given in Table 2. As shown in this table, the absorptions of 20 and 10 mm coarse aggregates and crushed sand at 24 h were 1.28, 1.62, and 1.85% by weight of aggregate, respectively. Moisture contents of the coarse and fine aggregates ranged from 0.05% to 0.18% and represented about 5–10% of their absorption capacity. ASTM C494 Type D water reducing and retarding admixture was used. Table 3 presents the specific mix proportions.

Table 1
Experimental program.

Aggregate condition	Without admixture		With admixture
	w/c ratio = 0.60	w/c ratio = 0.55	w/c ratio = 0.50
Wet	Mix 1	Mix 3	Mix 5
Air-dry	Mix 2	Mix 4	Mix 6

4. Preparation of aggregates for mixing

4.1. Air-dry condition

In this condition, the dry fine and coarse aggregates were weighed in the same laboratory environment. The quantity of water needed to substitute the 24 h absorption was added to the dry aggregates at the time of mixing in addition to the required free water.

4.2. Wet condition

The air-dry fine and coarse aggregates for each mix were kept in a plastic container after weighing and were wetted by adding the total mixing water needed for the mix (free water and water required to substitute the 24 h absorption of aggregates). The container was tightly covered by a polyethylene sheet to prevent evaporation and to make sure that aggregates were kept wet for 24 h until the time of mixing. This method was used for all mixes related to wet aggregates.

5. Mixing and testing procedures

All mixtures were mixed in a conventional rotary drum concrete mixer in accordance with the ASTM C 192 procedure. The ambient temperature and relative humidity in the laboratory during mixing and measuring slump loss were in the range of 21–23 °C and 30–35%, respectively. After completion of mixing, the concrete was discharged into wheelbarrows which were then covered with a polyethylene sheet to prevent evaporation. The initial concrete temperature and initial slump tests were performed immediately according to ASTM C 1064 and ASTM C 143, respectively. The initial concrete temperatures of all mixes were in the range of 24–27 °C.

The slump was re-measured at 15, 30, 60, 90, 120, and 150 min after measuring the initial slump. It should be noted that the concrete in the wheelbarrows was remixed manually for about 1 min before each slump measurement was taken. Compressive strength tests were performed on 150 × 150 × 150 mm cube specimens following BS 1881 part 116. From each mix, three cubes were tested at 7 and 28 days each.

Table 2
Absorption of aggregates at different times of immersion in water.

Type of aggregates	Aggregate absorption	Duration of immersion of aggregate in water			
		15 min	1 h	3 h	24 h
20 mm coarse aggregate	% By weight of aggregate	0.96	0.98	1.03	1.28
	% of 24 h absorption	75	76	80	100
10 mm coarse aggregate	% By weight of aggregate	1.13	1.15	1.35	1.62
	% of 24 h absorption	70	71	83	100
Crushed sand	% By weight of aggregate	1.23	1.26	1.48	1.85
	% of 24 h absorption	66	68	80	100

Table 3
Mix proportions.

Mix no.	Cement (kg/m^3)	20 mm coarse agg. (kg/m^3)	10 mm coarse agg. (kg/m^3)	Crushed sand (kg/m^3)	w/c ratio	Total mixing water (kg/m^3)	Admixture (L/100 kg cement)
1 and 2	350	630	420	780	0.60	239.3	–
3 and 4	350	630	420	780	0.55	221.8	–
5 and 6	350	630	420	780	0.50	204.3	0.30

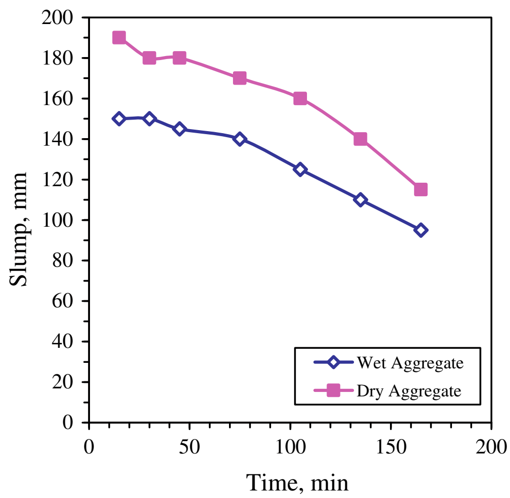

Fig. 1. Variation of slump with elapsed time for concrete mixes with 0.60 w/c ratio and without retarder.

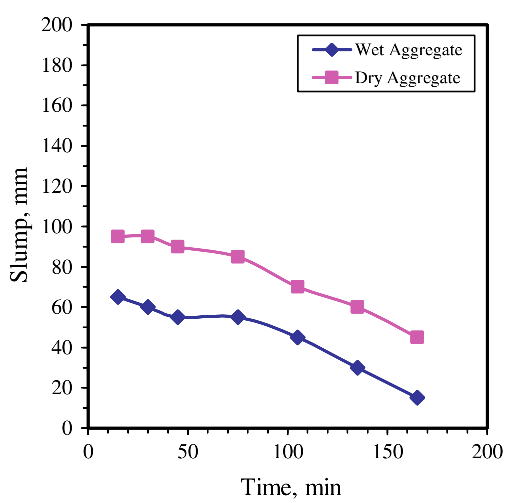

Fig. 2. Variation of slump with elapsed time for concrete mixes with 0.55 w/c ratio and without retarder.

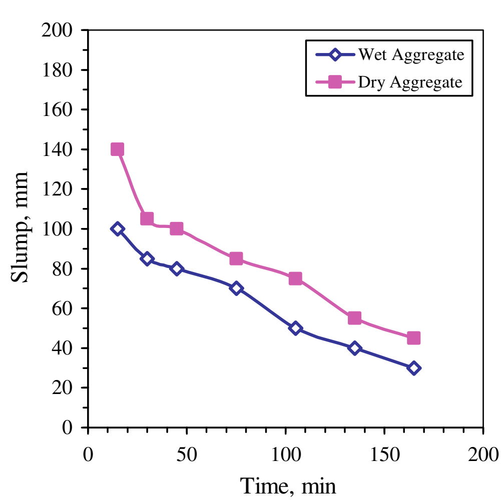

Fig. 3. Variation of slump with elapsed time for concrete mixes with 0.50 w/c ratio and with 0.3% retarder.

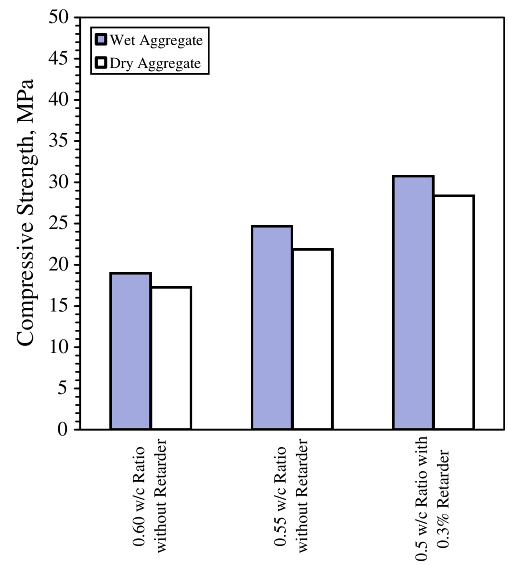

Fig. 4. Variation of compressive strength at 7 days with w/c ratio for all mixes.

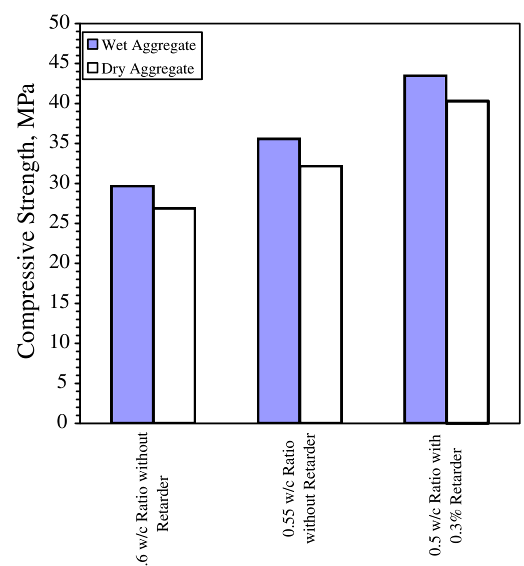

Fig. 5. Variation of compressive strength at 28 days with w/c ratio for all mixes.

6. Test results and discussions

The variations of slump with respect to time for all mixes are plotted in Figs. 1–3. The results show that the initial slump values of all mixes with dry aggregates were 30–40 mm higher than those with wet aggregates. In addition, the figures indicate that the rate of slump loss for the two conditions of wet and dry aggregates is approximately constant, even for mixes where the setting time of concrete was extended using a retarding admixture. This result indicates that aggregate absorption had diminished just after the time of measuring the initial slump.

The average 7 and 28 days compressive strengths for all mixes are presented in Figs. 4 and 5, respectively. The results clearly show that the compressive strengths at 7 and 28 days for all the mixes with wet aggregates were 8–12% higher than those for mixes with dry aggregates. This indicates that the dry aggregates did not fully absorb the total water added for absorption. As a

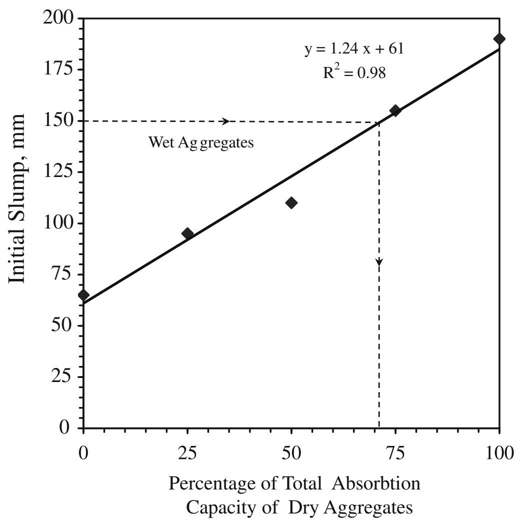

Fig. 6. Relationship between initial slump and percentage of total absorption capacity of dry aggregates.

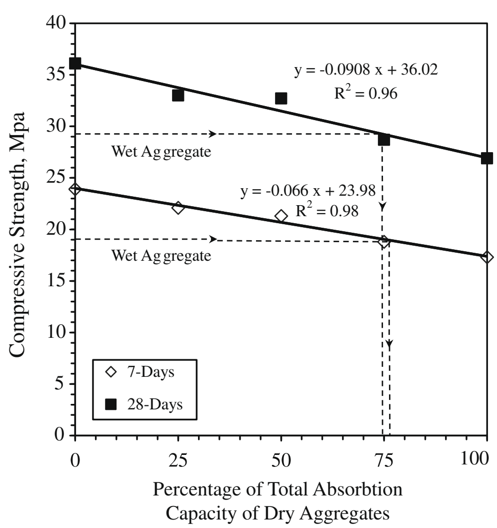

Fig. 7. Relationship between compressive strength at 7 and 28 days and percentage of total absorption capacity of dry aggregates.

result, this extra water in addition to the existing free mixing water increased the effective w/c ratio.

The reduction of compressive strength is consistent with the observed effect of dry aggregates on initial slump shown in Figs. 1–3, indicating a limited absorption of water by dry aggregates in concrete mixes beyond time of initial slump measurement. Thus, absorption affects only the initial slump with a limited influence on overall slump loss. This occurrence may be ascribed to the aggregates being coated with cement paste which closed the pores and prevented further absorption by the aggregates [8].

6.1. Verification of test results

To verify the test results, the actual amount of water absorbed by dry aggregates when mixed in concrete was further investigated by considering four additional mixes with dry aggregates. Different substitutes of water were needed for absorption (0%, 25%, 50%, and 75%) using a 0.6 w/c ratio without admixture. The only tests conducted for these particular mixes were the initial slump and compressive strength at 7 and 28 days. The results from these tests were compared with the results of Mix 1 (see Table 1) which were carried out with wet aggregates at the same 0.6 w/c ratio.

Figs. 6 and 7 show the variations of initial slumps and the average compressive strengths at 7 and 28 days with the percentage of total water absorption for dry aggregates, respectively. Fig. 6 shows that the initial slump of the mix with wet aggregates of a 0.6 w/c ratio intersects with that of the mix with dry aggregates with same w/c ratio and 75% of water absorption. Fig. 7 shows the same observation for compressive strengths at both 7 and 28 days. Thus, limestone aggregates used in this study with an absorption capacity of 1.3–1.9% can absorb about 75% of their total potential water absorption when mixed in concrete, whereas 25% will remain as free water. This result is similar to the 80% figure given by ASTM C192 for low absorption aggregates (less than 1.0%) [11].

7. Conclusions

Based on the test results, the following can be drawn:

1. Dry limestone aggregates used in this study did not fully absorb the water added to compensate for absorption, thus leading to an increased effective w/c ratio of the mixes.
2. The increase in the effective w/c ratio for concrete mixes with dry aggregates resulted in an increase of about 30–40 mm of initial slump and a reduction of about 8–12% of compressive strength when compared with mixes using wet aggregates.
3. The constant rate of slump loss for mixes with dry aggregates suggests that absorption has diminished after 15 min of mixing, even for mixes where the setting time of concrete was extended using a retarding admixture. Thus, slump loss is caused mainly by evaporation and cement hydration.
4. Limestone aggregates used in this study with an absorption capacity of 1.3–1.9% can absorb about 75% of their total absorption capacity when mixed in concrete. This outcome is comparable to the value of 80% given by ASTM C192 for low absorption aggregates (less than 1.0%).

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