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Effect of Curing on the Strength of Ready-Mixed Concrete in Hot and Humid Climate

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ABSTRACT. The results of an investigation of concrete quality of 17 ready-mixed concrete producers in Jeddah, Saudi Arabia are presented. The study covers the quality of constituent materials and the effect of curing method on the compressive strength of ready-mixed concrete. The curing methods used were standard, sprinkling with water, and covering with wet burlap. Test results show that the constituent materials used were of high qualities and the concrete specimens covered with wet burlap and sprayed twice daily for seven days gave comparable 28-day compressive strength to that of the specimens cured under standard conditions.

1. Introduction

Designers in the construction industry usually classify concrete by its compressive strength especially at the age of 28 days. Concrete compressive strength is influenced by the properties and proportions of its constituents and by the mixing, casting and curing methods. Until the mid-seventies most of the concrete used in the city of Jeddah was cast *in situ*. However, the city has since witnessed large expansion and extensive development needing huge quantities of concrete. Ready-mixed concrete was introduced to augment the supply of the needed concrete. Annual production of ready-mixed concrete increased from a mere 50,000 m^3 by one supplier to a current quantity of 1,500,000 m^3 by 25 producers. This study concentrates on the effect of curing methods on the compressive strength of ready-mixed concrete in hot and humit climate typified by the environmental conditions in the city of Jeddah located on the Red Sea coast of Saudi Arabia.

ACI Committee 305[1] defines hot weather as any combination of high air temperature, low relative humidity and wind velocity tending to affect the quality and properties of fresh or hardened concrete. In the city of Jeddah, the day time summer temperature reaches up to 50°C in the shade. Relative humidity in the region can be above 90% during summer and drops to 30% within a short period of time. In a typical summer day, the maximum energy level due to solar radiation reaches 1.08 kW/hr/m^2 with a total of 9 kW/hr/m^2. Khallaf[2] studied the influence of hot weather conditions on the properties of concrete used in the construction of a massive concrete foundation for a large building project in Jeddah. He showed that although good construction practice was followed, evaporation rate for the concrete cast during the noon period of a hot summer day was 1500 gm/m^2/hr and occurred 4 to 5 hours after casting which exceeded the limit of 1000 gm/m^2/hr specified by ACI Committee 305[1] as the limit when concrete will be susceptible to plastic shrinkage cracking. He found that shading the concrete from direct sun rays reduced evaporation rate by more than 50%.

2. Cast-*In situ* Concrete Construction

Ready-mixed concrete with reasonable quality control is generally used in the construction of large buildings in Jeddah. However, construction of 2-4 storey buildings, the predominant type of existing buildings carried out mainly by small contractors. In such cases, concrete is produced at building sites by labourers without the bare minimum of equipment such as a small mixer. Proportioning of concrete mix is done by volume without proper control on material quality and quantity. Water is added to the convenience of the person in charge of the mixer for obtaining very workable mix, resulting always in excessive water-cement ratio. On most construction projects, curing is carried out by sprinkling water twice daily for up to 7 days. However, in many cases concrete is left to cure in air dry condition. Shweiki and Al-Wagdany[3] evaluated the quality of *in situ* concrete construction in Jeddah. Out of 30 projects surveyed, 12 of the fine aggregate, 28 of the coarse aggregate, 29 of the measured slump, and 24 of the concrete compressive strength were not within the acceptable ranges. Mashat and Basyouni[4] conducted a similar investigation on the *in situ* concrete construction in the city of Makkah Al-Mukarramah. Out of 30 projects surveyed, 16 of the fine aggregate, 29 of the coarse aggregate, 11 of the fine material content, 28 of the measured slump, and 16 of the compressive strength were not within the acceptable ranges.

3. Ready-Mixed Concrete Constituent Materials

High quality materials are used in the ready-mixed concrete produced in Jeddah. Crushed-rock coarse aggregate having angular shape whose physical properties are given in Table 1 is used. Most of the gradations fall within the ASTM C-33 limits while the others tend to lie outside the coarser side. Natural fine aggregate is obtained from valleys near Jeddah and their physical properties are given in Table 2. The majority of gradations lie within the ASTM C-33 limit and those outside the

TABLE 1. Coarse aggregate characterizations.

Source	Sources # 1				Source # 2			Source # 3			Source # 4	
Normal size (1)	25 mm (2)	20 mm (3)	12 mm (4)	10 mm (5)	20 mm (6)	12 mm (7)	10 mm (8)	20 mm (9)	12 mm (10)	10 mm (11)	20 mm (12)	10 mm (13)
Fineness modulus	8.00	7.53	6.58	5.69	7.47	6.29	5.79	8.38	6.63	5.95	7.36	6.24
Fines (%)	2.4	3.7	5.1	6.5	2.0	2.6	6.8	2.5	3.8	3.9	2.2	3.4
Specific gravity	2.85	2.83	2.82	2.85	2.81	2.77	2.72	2.77	2.77	2.76	2.73	2.76
Unit weight (g/cc)	1.65	1.64	1.56	1.55	1.61	1.50	1.49	1.56	1.56	1.49	1.57	1.43
Absorption %	0.50	0.91	1.00	1.11	0.86	1.58	2.18	0.40	1.57	1.64	1.16	1.18
Impact value %	3.14	3.62	6.50	5.56	4.10	5.34	5.93	4.46	8.90	8.46	4.93	7.86
Abrasion loss %	8.50	9.00	10.98	14.62	9.86	11.76	16.62	8.18	14.10	18.34	12.53	14.47
Crushing value %	-	7.75	8.45	10.50	9.25	12.48	11.23	9.74	11.87	10.40	11.71	14.37

limits tend to lie on the finer side. Types I and V portland cement commonly used, and type I is used to produce about two thirds the quantity of ready-mixed concrete in Jeddah. All producers use different types of admixtures, and sometimes two types of admixture are used simultaneously. Clean potable water is used by all ready-mixed manufacturers.

TABLE 2. Fine aggregate characterizations.

Source (1)	# 1 (2)	# 2 (3)	# 3 (4)	# 4 (5)	# 5 (6)	# 6 (7)	# 7 (8)	# 8 (9)
F.M.	2.28	2.44	2.27	2.18	2.22	2.11	2.30	1.99
Specific gravity	2.51	2.68	2.44	2.71	2.43	2.71	2.71	2.70
Unit weight (gm/cc)	1.76	1.75	1.74	1.72	1.73	1.74	1.74	1.69
Absorption %	0.83	0.83	0.86	1.10	0.78	0.96	0.77	1.03

4. Effect of Curing Methods on Strength

Samples from seventeen construction sites in Jeddah were collected following ASTM Standard C172, (sampling freshly mixed concrete). The samples were cast

following ASTM C-31 standard procedures. The concrete specimens [150 mm (6 in.) cube] were left in mould at site for twenty four hours after which the specimens were demoulded and transported to the laboratory. The specimens were divided into three groups, two cubes each. The first group was submerged in water inside the laboratory for standard curing. The other two groups were left outside the laboratory to simulate curing practices followed in the region which consist of sprinkling with water twice daily for seven days with and without burlap covering. Data on cement content, water/cement ratio and slump of the concrete used were obtained from the ready-mixed concrete producers and are listed in Table 3. The average slump from the seventeen sites was 104 mm (4 in.) compared with the average slump of 174 mm (7 in.) of the cast *in situ* concretes obtained from a previous study[3]. Figure 1 shows that excessive slump is more common in cast-*in situ* concrete than in ready-mixed concrete for the two design strength categories of 21 and 28 MPa.

TABLE 3. Properties of ready-mixed concrete.

Site no.	W/C	Wt. of cement content (kg/m^3)	Slump (mm)	Compressive strength (MPa)			Design strength (cube) (MPa)
				Standard curing	Sprinkling + burlap	Sprinkling	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0.45	400	135	27.2	29.4	27.4	24
2	0.44	400	70	36.5	37.1	34.4	28
3	0.54	400	95	36.7	35.6	33.4	28
4	0.51	350	95	32.2	31.7	30.0	28
5	0.50	350	140	26.7	26.6	26.0	24
6	0.54	350	90	32.9	33.5	33.0	28
7	0.45*	400	125	19.7	25.4	24.7	34
8	0.51	350	90	29.8	27.3	25.0	24
9	0.50	350	110	32.5	34.4	31.5	24
10	0.50	400	120	23.9	23.8	29.6	28
11	0.50	300	110	37.2	38.0	29.3	24
12	0.50	350	90	33.3	32.3	30.3	24
13	0.44	350	110	30.1	21.4	24.0	21
14	0.45	400	105	32.8	29.6	28.4	28
15	0.45	400	90	33.3	35.2	32.2	28
16	0.50	300	110	37.4	38.8	36.5	28
17	0.43	300	85	35.2	34.0	30.9	21

*Additional water was added at the site, *i.e.*, actual w/c >> 0.45.

Figure 2 compares the average compressive strength of ready-mixed and cast-*in situ* concrete specimens cured under standard curing conditions. The coefficient of variation is higher in the cast-*in situ* concrete reflecting poor quality control on proportioning, mixing and probably on the quality of the material used. Figure 2 also shows that the compressive strength of all ready-mixed concrete specimens exceeded the design strength values. Figures 3 and 4 show the effect of curing method on the compressive strength of ready-mixed concrete for the design strength category of 24

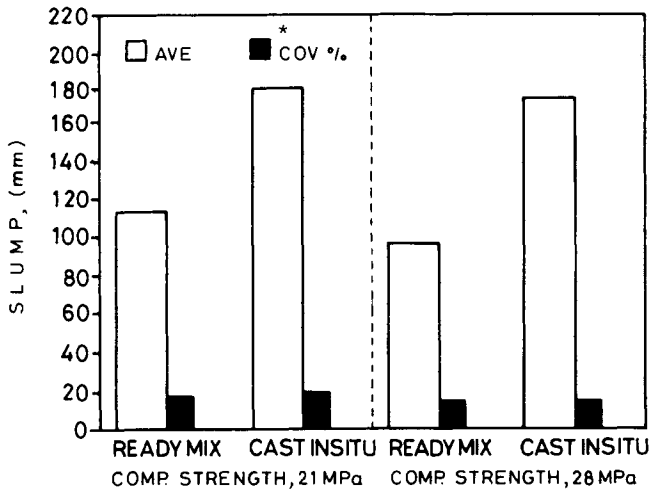

FIG. 1. Comparison of slumps of ready-mixed with cast-*in situ* concrete.
*COV : Coefficient of variation.

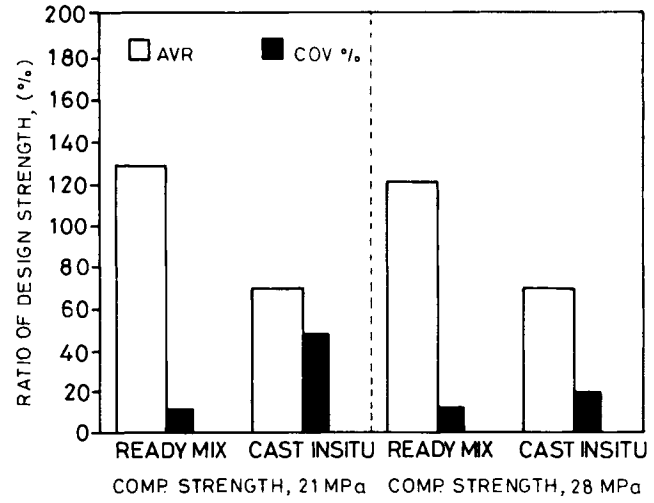

FIG. 2. Strength comparison of ready-mixed and cast-*in situ* concrete under standard curing condition.

and 28 MPa (3500 and 4000 psi), respectively. Both figures show that comparable compressive strengths were obtained using either the standard curing method or the two types of sprinkling method. The sprinkling method without burlap covering gave lower 28-day compressive strength, but in no case was it lower than the design strength.

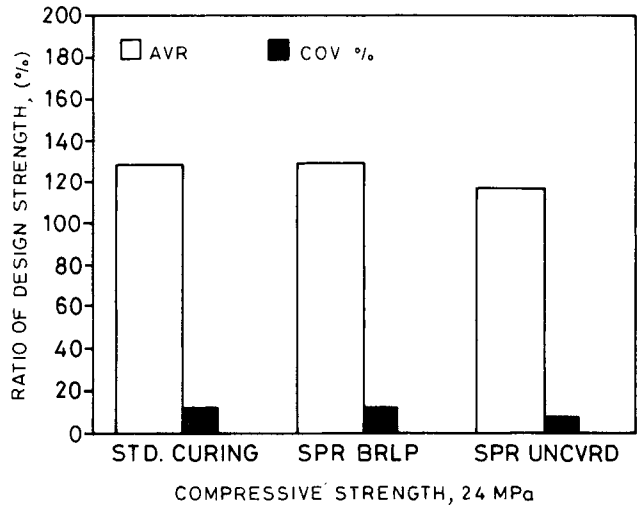

FIG. 3. Effect of curing method on the compressive strength of ready-mixed concrete (f'_c = 24 MPa).

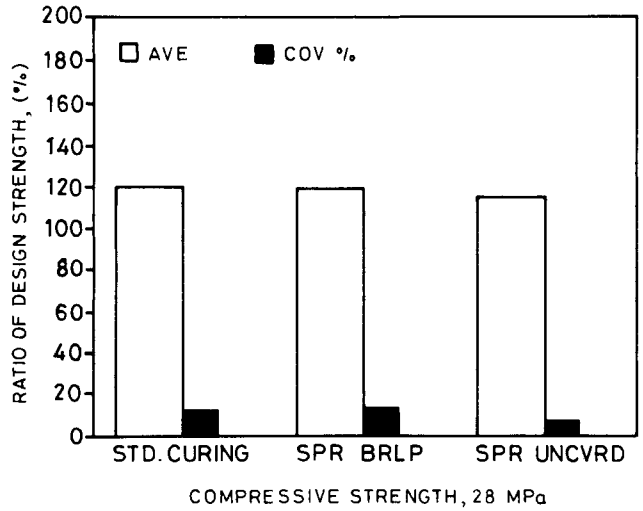

FIG. 4. Effect of curing method on the compressive strength of ready-mixed concreted (f'_c = 28 MPa).

The strength of concrete at 28 days is usually specified by designers for standard cured specimens. However, standard curing is not practicable in the field. The 28-day compressive strength of the sprinkled or dry air cured may not effectively represent the long term strength and durability of concrete and further study is recommended in this area.

Conclusion

1. Use of cast-*in situ* concrete following current practices is not recommended due to the large strength variation which is lower than the specified strength. In cases where its use can not be avoided, the design strength should be based on either statistical data or empirical relationships to overcome the factors which cause the reduction in the actual strength of cast-*in situ* concrete.

2. The 28-day compressive strength of ready-mixed concrete specimens sprinkled twice daily for seven days and covered with burlap is comparable with that of concrete cured under standard curing method.

3. The 28-day compressive strength of the ready-mixed concrete specimens sprinkled twice daily for seven days without burlap covering was less than that of the specimens cured by the standard method by only about 7%, indicating no significant difference.

4. Ready-mixed concrete provides quality material which satisfies design strength and is recommended for construction.

Acknowledgment

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References

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تأثـــير المعالجـة على نوعيـة الخرسانـة الجاهـــزة في البيئـــة الحارة والرطبـــة

فيصل فؤاد وفا و صبري أحمد شحاته
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المستخلص . يقـدم هذا البحث نتـائـج دراسـة حقلية ومعملية أُجريت لمعرفة نوعية الخـرسـانـة التي يُنتجهـا ١٧ مصنعًـا للخرسانة الجاهزة في مدينة جـدة بالمملكة العربية السعـودية . تغطي الدراسة نوعية المواد المستخدمة وتأثير طرق المعالجة على قوة انضغاط الخـرسـانة . استُخدم في هذا البحث ثلاث طرق للمعالجة ، وهي : الطريقة القياسية (المغمـورة في المـاء) ، والتغـطية بالخيش المبلل ، والـرش بالمـاء . علمًا بأن الـطريقتـين الأخيرتين شائعتا الاستعمال في صناعة البناء المحلية . أظهرت النتائج أن المواد المستخدمة في جميع مصانع الخرسانة الجاهزة هي ذات نوعية عالية وأُعطت العينات الخرسانية المغطاة بالخيش والمرشوشة مرتين يوميًا بالمـاء لمدة سبعة أيام نتائج مماثلة تقريبًا لتلك المعالجة بالطريقة القياسية عند اختبارها بعد ٢٨ يومًا .