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Concrete mixture design for hot weather: experimental and statistical analysis

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I would like to congratulate Professors Gahtani, Abbasi and Al-Amoudi for their excellent contribution to the world of concrete in hot weather. The paper gives valuable guidance to the proportioning of concrete mixtures in the Arabian Gulf, in particular. In my opinion, the value of their contribution and the relevance of this work could have been enhanced considerably by testing relatively bigger sized specimens. One of the main causes of the regression in both strength and durability of concrete structures in hot–dry exposure conditions is the setting up of thermal gradients which cause subsequent cracking and microcracking. A 75×150 mm cylinder is simply too thin to model this behaviour. A 150×300 mm or at least 100×200 mm cylinder could have better simulated the rise of temperature in the various elements of a structure. Perhaps, monitoring on both 75 and 150 mm size diameter cylinders would have highlighted the effect of internal temperature rise during the early hydration of cement and its subsequent effect on the strength of concrete. In addition, monitoring of temperature rise of concrete within the initial hydration period would have been very informative.

I have four comments to offer on the conclusion ‘that lowering the concrete mixture temperature at placement alone, as recommended in the codes of practice, does

not eliminate the adverse effect of hot weather on compressive strength’.

First, in light of the discussion in paragraph 1, the specimen size used in the observation was so thin that the adverse effects of thermal cycling due to temperature rise within the specimen were not operational. Second, the adverse effects of high temperature during placement are normally absent in the first 28 days; rather, often an increase in strength can be witnessed. The detrimental effect of such regimes on compressive strength is often manifested at a later age.^{28,29} Third, and more important, it is the durability of concrete structures which is of importance, as outlined by the authors in their introduction to of the paper. It is certainly true that in certain extreme exposure conditions, such as those that prevail in the Arabian Gulf, concrete structures have got to be designed both for strength and durability.^{30,31} Compressive strength is not synonymous with durability. Fourth, the need for proper curing is all the more important in hot–dry and windy exposure conditions. Again, the extent of curing achieved in a concrete at 26°C and say 36°C temperature by sprinkling water on moist burlap twice a day is not equal. The concrete specimens cured at 36°C, by sprinkling water on a moist burlap twice a day, virtually do not get any curing. Again, the effects or lack of initial

curing are much more pronounced on the long-term strength and durability rather than the short-term, 28 day strength.³² The conclusion 'that the compressive strength of the specimens prepared at normal laboratory temperature but cured in hot weather was about 6–20% lower than that of the specimens prepared and cured at the normal laboratory temperature', is in reality due to 'lack of curing' rather than to curing at high temperature. In fact, the authors have said this succinctly in the first paragraph, page 101 of the paper.

The Australian Standard³³ and, I guess, other standards require compressive strength to the nearest 0.5 MPa only (Table 2 of the paper). Similarly, slump is expressed to the nearest 5 or 10 mm only.

Reply by the authors

The authors appreciate the relevant and valuable comments of Professor M. N. Haque. No doubt, as rightly pointed out by him and also by us in our paper, durability is an important aspect of the performance of concrete structures. However, durability was not intended to be the objective of this paper; it has been the subject of other research studies carried out at KFUPM.^{1,2,18} This paper concentrates on the method of concrete mix design for hot weather to achieve the required 28 day compressive strength on which the design of concrete structures in the codes of practice is based.³⁴ Therefore, the emphasis of this paper was on the 28 day strength rather than the early-age strength, which is generally higher at elevated temperatures owing to faster hydration of cement in the first few days after preparation of concrete. Our results have confirmed this. In fact, our experimental programme compares the 3, 7, 14 and 28 day strengths.³ The detrimental effects of hot weather on the compressive strength are clearly manifested beyond 7 days.^{11,35}

Most importantly, this paper considers the *in situ* conditions of preparation, placement and curing of concrete in hot weather which involve nearly all the factors that have a detrimental effect on the quality of concrete. As stated on page 97 of the paper, all the materials were placed in the sun to raise their temperature in natural conditions and, since the entire work of mixing and placement of concrete and preparation of the specimens had to be done quickly to obtain consistent and meaningful results with portable laboratory-type equipment, all the required specimens for each mix had to be prepared out of one batch, thereby limiting the quantities of materials to be handled in one operation, and hence restricting the size of cylindrical specimens to 75 × 150 mm. Moreover, since it was not intended to go into the durability aspect, it was not considered necessary to monitor the temperature rise within the specimens, or the internal disorder and microcracking, for which larger-size specimens would no doubt have been preferable, as rightly pointed out by Professor Haque.

Regarding Professor Haque's comments on the effects of curing, the curing was not carried out at a constant high temperature during the entire curing period, but was done in the natural atmosphere so as to correspond to the *in situ* conditions (i.e. the curing temperature varied with the natural atmospheric temperature). No doubt the first sprinkling of water in the morning provided curing water for a short period owing to the faster rate of evaporation at a quickly rising temperature, but the second sprinkling, which had been done in the late afternoon, did provide curing water (although not as much as would be available in a curing tank inside the laboratory), as it was done under a falling temperature in the evening and at night with a much reduced rate of evaporation. Therefore, the contention of Professor Haque that the reduction in the strength was due to the 'lack of curing' is not correct. What is stated on page 101 of the paper is the correct position, which describes two reasons for the reduction in strength, the second one being the 'insufficient' hydration of cement that takes place owing to the 'reduced' availability of curing water as stated above.

Furthermore, as regards the specimens which were prepared inside the laboratory at 26°C (simulating the condition in which all the necessary precautions are taken to reduce the concrete temperature at placement) and then immediately transferred to the '*in situ*' hot weather, this resulted in subjecting the specimens to a 'temperature shock', thereby creating internal disorder, which is an added factor, besides curing, that could cause some reduction in strength. This justifies the statement in the paper that 'lowering the concrete temperature at placement alone, as recommended in the codes of practice, does not eliminate the adverse effect of hot weather on compressive strength'. Contrary to this, as determined through an earlier published work,³⁵ concrete can be prepared with appropriate mixture proportions (including w/c ratio) to obtain the required slump and compressive strength in hot-weather conditions, and this is what this paper aims at, as it gives a method of selecting the mixture proportions of concrete constituents for this purpose.

Regarding the data of compressive strength and slump, the authors would like to mention that these values (Table 2) were initially determined in psi and inches, respectively,³ and were then converted accurately to MPa and mm exclusively for the purpose of this paper. We, however, decided that the data should be recorded to as much accuracy as possible in order to be utilized for the statistical analyses presented in the paper under discussion. Therefore, the accuracy of measurement of the data reported in Table 2 is amply justified for the purpose of fulfilling the cardinal objective of this investigation, namely the development of reliable models for predicting the strength and slump of concrete cast and cured under elevated-temperature conditions.

References

28. NEVILLE A. M. *Properties of Concrete*, 4th edn. Longman, Harlow, 1995.
29. MEHTA, P. K. and MONTERIO P. J. H. *Concrete: Structure, Properties and Materials*, 2nd edn. Prentice Hall, New Jersey, 1993.
30. MEHTA P. K. Durability-critical issues for the future. *ACI, Concrete International*, 1997, **19**, No. 7, 27–33.
31. NEVILLE A. M. Maintenance and durability of structures. *ACI, Concrete International* 1997, **19**, No. 11, 52–56,
32. AL-KHAIAT and HAQUE M. N. Effect of initial curing on early strength and physical properties of a lightweight concrete. *Cement and Concrete Research*, 1998, **28**, No. 6, 859–866.
33. STANDARDS AUSTRALIA *Method of Testing Concrete*. Standards Australia, Australia, 1983, AS1012.
34. ACI COMMITTEE 318. *Building Code Requirements for Reinforced Concrete*. American Concrete Institute, Detroit, 1995.
35. ABBASI A. F. and ALAM M. S. Compressive strength of concrete in hot weather. *Internal Journal of Housing Science, Florida*, 1982, **6**, No. 2.