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Hot Weather Concreting with Admixtures

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Abstract

The adverse effects of elevated temperatures on the properties of the fresh concrete, namely increased water demand, shorter setting times and increased slump loss, are briefly discussed, and the possible use of chemical admixtures (ASTM C 494) to overcome these adverse effects, is examined in the light of present knowledge. The effect of water reducing and retarding admixtures (type D, ASTM C494) on plastic shrinkage and plastic shrinkage cracking, and the effect of fly ash class F (ASTM C 618) on slump loss, are also discussed. It is concluded that type D admixtures accelerate, rather than slow down the rate of slump loss in concrete subjected to prolonged mixing, but such admixtures are advantageous when used to reduce water demand and to delay setting times. Fly ash was found to reduce significantly the rate and amount of slump loss of concrete with and without admixtures. It is suggested, however, that under hot weather conditions, the combined use of class F fly ash and type D admixtures is to be recommended. Both retarders and fly ash were shown to increase the susceptibility of fresh concrete to plastic shrinkage cracking. Accordingly, when used, extra care should be taken to protect the fresh concrete from drying. © 1998 Published by Elsevier Science Ltd. All rights reserved.

Keywords: hot weather concreting, chemical admixtures, slump loss, fly ash.

INTRODUCTION

Fresh concrete mixes stiffen with time, particularly if continuously mixed. This stiffening effect is reflected in a reduced slump and, accordingly, this phenomenon is referred to as 'slump-loss'. Under moderate weather conditions, the stiffening of the fresh concrete, and its associated slump loss, present no real problems because in practice, the concrete remains workable long enough to allow its handling, namely its transporting, placing, compacting and finishing, without any appreciable difficulties. Under hot weather conditions, however, this may not be the case, because the rate of stiffening, and the associated slump loss are both increased[1–3], and the initial and final setting times are both decreased[4–7] with the rise in temperature.

The above-mentioned effects of temperature on stiffening of the fresh concrete are well known and generally recognised. An accelerated slump loss and shorter setting times are, of course, undesirable because they reduce the length of time during which fresh concrete remains workable and can be handled properly and thoroughly compacted at the building site. In fact, the accelerated slump loss constitutes one of the major problems of hot weather concreting. There are some means that may be employed in order to overcome the practical problems associated with the accelerated slump loss,[8] and, in this respect, the possible use of chemical and mineral (fly ash) admixtures is considered further in the paper. The use of these admixtures, however, must be considered also with respect to their possible effect on plastic shrinkage cracking. Accordingly, this aspect is also discussed in the paper.

WATER DEMAND

One more aspect that must be considered with respect to hot weather concreting is the increase, with temperature, in the amount of mixing water that is required to impart a certain slump to a given mix, i.e. to impart the desired

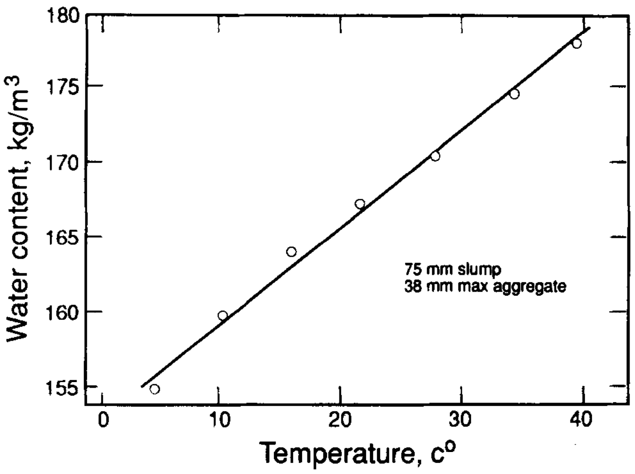

Fig. 1. Effect of temperature on the amount of water required to produce a 75-mm slump in a typical concrete. After US Bureau of Reclamation.[10]

consistency to a given mix.[9,10] This effect of temperature is demonstrated in Fig. 1 and is attributable to its accelerating effect on the hydration rate of the cement. As some time elapses from the moment that the water is added to the mix and the time that the slump is determined, the mix somewhat stiffens, and this stiffening is greater at higher concrete temperatures. Hence, in order to overcome this greater stiffening, more water must be added to the mix, i.e. the water demand is thereby increased.

The increase in water demand is undesirable because it increases the water cement ratio (W/C) and thereby adversely affects concrete properties. However, increasing the cement content, to obtain the required W/C ratio, is also undesirable because of the increased cost involved and the increased drying shrinkage of the concrete that, in turn, increases its susceptibility to cracking. It is self-evident that in order to avoid the undesirable effects of the increased water demand, water-reducing admixtures (WR) and a high-range water reducer (HRWR) should be considered.

SETTING TIMES AND SLUMP LOSS

As mentioned earlier, the stiffening of the fresh concrete, and the associated slump loss, are brought about mainly by the hydration of the cement. Some evaporation of the mixing water and, in some cases, also the absorption of water by dry aggregates may constitute additional causes. All these effects reduce the amount of the free water in the fresh concrete mix. Consequently, the fluidity of the mix is decreased, i.e. stiffening takes place.

The rate of the cement hydration increases with the rise of temperature and generally follows Arrhenius equation. It can be shown[8] that, based on this equation, the rise in the hydration temperature from 20°C to, say, 40°C, increases, in the first few hours, the hydration rate by a factor of 2.41. That is, the accelerating effect of temperature on the hydration rate of Portland cement is very significant indeed. This accelerating effect of temperature is, of course, well recognised and is supported by a considerable body of experimental data. It follows that a higher temperature, through its effect on the rate of hydration, will result in shorter setting times and a higher rate of slump loss. This effect is demonstrated, for example, in Figs 2 and 3. Of course, slump loss is further effected whenever loss of water through evaporation takes place.

In view of the preceding discussion, it may be expected that the use of retarding admixtures, by slowing down the rate of hydration, would slow down the rate of slump loss and thereby counteract the accelerating effect of temperature. Hence, the use of such admixtures should be considered under hot weather conditions. Noting the previous conclusion that water reducing admixtures are desirable under hot weather conditions, it may be further concluded that the use of water reducing and retarding admixtures (WRR) (i.e. type D admixtures in accordance with ASTM C 494), should be considered, rather than admixtures that merely reduce water demand and have no retarding effect (i.e. type B).

RETARDING ADMIXTURES

Retarding admixtures slow down the hydration of the cement and thereby delays its setting. Hence, due to the slower rate of hydration, a smaller amount of water is combined with the cement at a given time. It is to be expected, therefore, that the corresponding slump loss in such a mix at the time considered will be smaller than in a mix made without a retarder. In other words, it is to be expected that the use of retarding admixtures would reduce the rate of slump loss and, therefore, may be useful in overcoming the accelerating effect of tempera-

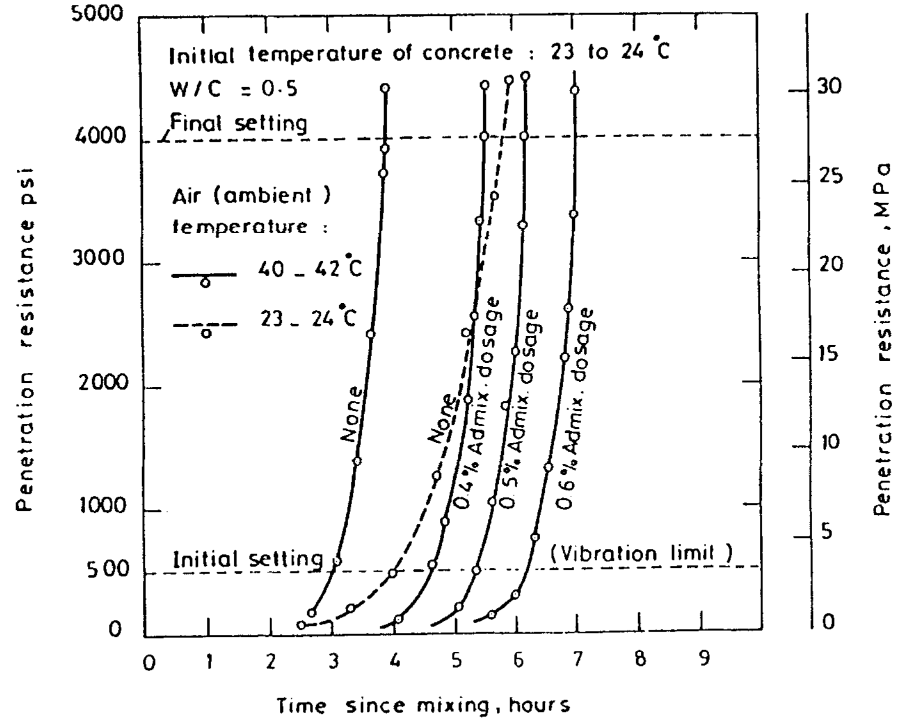

Fig. 2. Effect of temperature and type D admixture on standard penetration and setting times of concrete determined in accordance with ASTM C 403. After El-Rayyes.[7]

ture. Indeed, this conclusion, is supported by experimental data when the effect of retarders on the rate of stiffening is evaluated from their effect on the setting times of concrete when determined through its penetration resistance in accordance with ASTM C 403.[6,7] An example of this effect is presented in Fig. 2 from which it is clearly evident that the use of a certain water reducing and retarding admixture in different dosages delayed setting to an extent that overcame the accelerating effect of temperature.

The preceding conclusion, however, is not supported when the effect of retarders is evaluated from their effect on slump loss of concrete that is kept agitated from the time of mixing to the time of testing, i.e. under conditions that simulate ready-mixed (transported) concrete. Relevant data of concrete tested accordingly are presented in Fig. 4. It is clearly evident from these data that the presence of WRR admixtures, depending on their specific type and dosage, actually increased, rather than decreased, the rate of slump loss[12]. Similar data, presented in Fig. 5, and some other data of many others,[1,13–16] confirm this somewhat unexpected observation, and give rise to the question of whether or not type D admixtures, and perhaps also type G high range water reducing and retarding admixtures (ASTM C 494), may be recommended in hot weather conditions to overcome slump loss.

The increased slump loss observed when type D admixtures were used warrants some explanation because these types of admixtures do retard setting when determined from penetration resistance in accordance with ASTM C 403. The seemingly contradictory behaviour may be attributed to the difference in the test procedures involved, i.e. while the increased slump loss was observed in concrete that was subjected to continuous agitation the time of setting is determined on a concrete that remains undisturbed.

Several theories have been advanced to explain the mechanism of retardation.[17] The adsorption theory suggests that the admixture is adsorbed on the surfaces of the unhydrated cement grains, and thereby prevents the water from reacting with the cement. Another theory, the precipitation theory, suggests that the retardation is caused by the formation of an insoluble layer of calcium salts of the retarder on the hydration products. Continuous agitation of the fresh concrete results in a ‘grinding effect’, which, among other things, can be considered to cause ‘peeling off’ of the adsorbed layer of the retarder or, alternatively, the precipitated layer of the calcium salts, whatever the case may be, from the surface of the cement grains. Hence, when the concrete is kept continuously agitated, the retarding mechanism fails to operate.

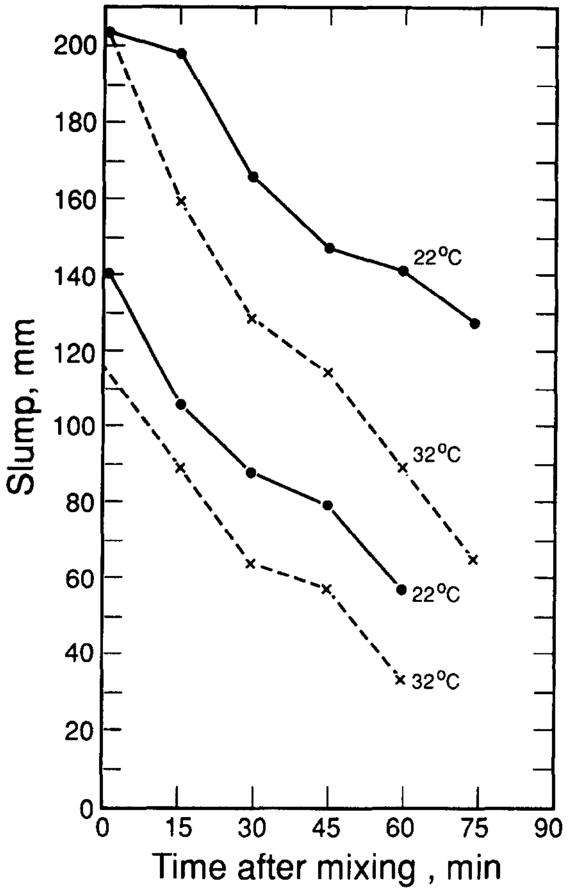

Fig. 3. Effect of temperature on slump loss of concretes of plastic and wet consistency cast at the temperatures of 22°C (o) and 32°C (x). After Hampton.[2]

The preceding mechanism, although it may explain why retarders fail to operate in continuously agitated concrete, does not explain their accelerating effect. It could be suggested that once the retarding mechanism is not operative any more, type D admixtures act merely as water-reducing admixtures and thus lower the amount of mixing water. Less water content implies a smaller spacing between the solid particles in the fresh mix. Consequently, in such a mix, due to the greater proximity of the particles, the hydration products thus formed are likely to bridge between the particles at an earlier stage than in a mix that contains a greater amount of water, and the spacing between the particles is greater. Hence, stiffening is brought about earlier, and this, in turn, explains the accelerating effect of the admixtures in question on slump loss. These theories notwithstanding, experimental data clearly indicate that type D admixtures increase, rather than decrease, the rate of slump loss in concrete that is subjected to prolonged mixing.

In view of the above, it could be questioned again as to whether or not the use of type D admixtures is to be recommended when prolonged mixing is involved, and particularly in hot environments that further aggravate the problem. In this respect, it should be noted that once agitation is stopped, i.e. when the concrete is placed and compacted, retardation is expected to take place, and this retardation is advantageous when the possibility of cold joints,

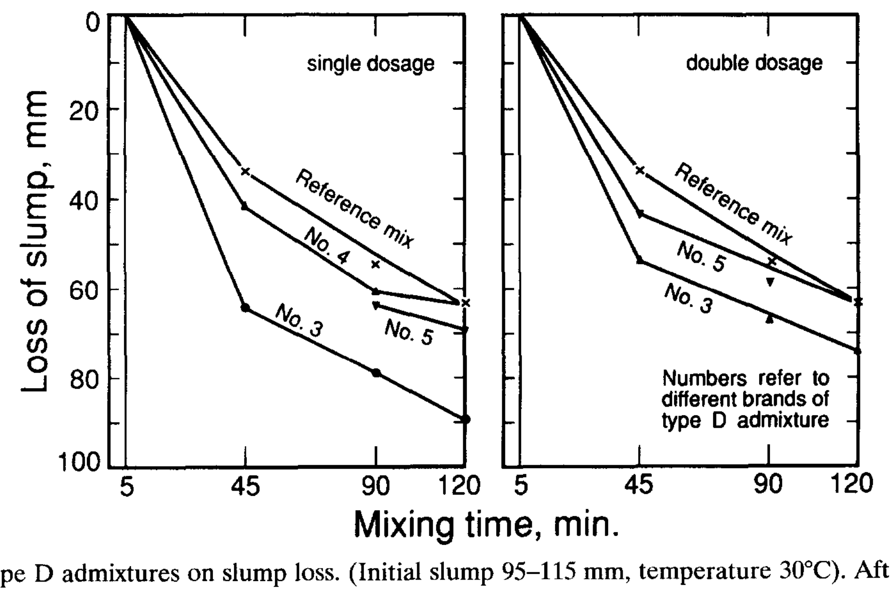

Fig. 4. Effect of type D admixtures on slump loss. (Initial slump 95–115 mm, temperature 30°C). After Ravina.[11]

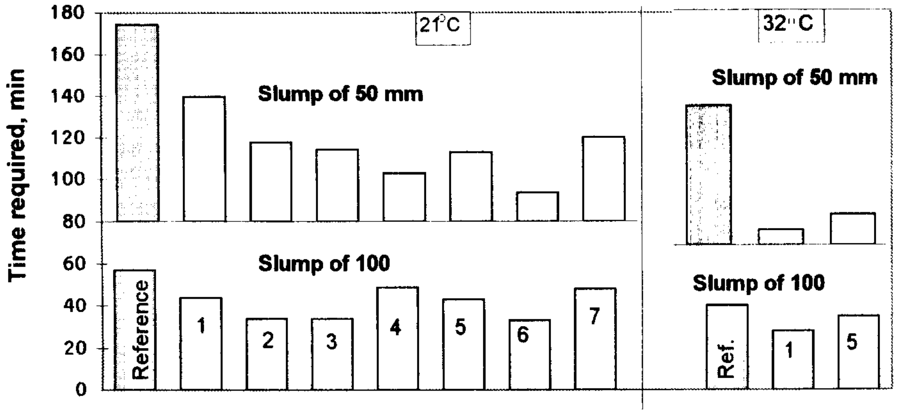

Fig. 5. Effect of type D admixtures (1–4) and type G high-range water reducing admixtures (5–7), on the time required for the fresh concrete to reach the slump of 100 and 50 mm (initial slump 165 ± 10 mm). After Ravina and Soroka.[12]

etc. is considered. Moreover, noting that increasing the initial slump constitutes one of the means that may be used to counteract the accelerating effect of temperature[8], type D admixtures may be utilised to produce more fluid mixes rather than to reduce water demand.

The use of type D admixtures should also be considered with respect to their possible effect on plastic shrinkage cracking. Plastic shrinkage cracking occurs when the induced tensile stress, brought about by the loss of water from restrained concrete elements, and particularly concrete slabs, exceeds the tensile strength of the fresh concrete. It follows that the likelihood for plastic shrinkage cracking to occur increases with the increase in plastic shrinkage and the decrease in the rate of strength development. The retardation effect of the admixtures delays the strength development and thereby, accordingly, the likelihood of plastic shrinkage cracking occurring increases. Moreover, it was shown[18] that plastic shrinkage is greater in retarded cement mortars than in their unretarded counterparts (Fig. 6). Indeed, it was reported[19] that concretes and mortars whose set was delayed by admixtures nearly always showed serious plastic cracking in the laboratory as well as in the field. Hence, it may be concluded that the use of a type D admixture aggravates the problem of plastic shrinkage cracking. That is, the likelihood of plastic shrinkage cracking to occur should be considered greater under hot, and particularly hot and dry, weather conditions, when retarders are used. Accordingly, extra care should be taken under such conditions to protect the fresh concrete from drying as soon as possible after placing and finishing.

FLY-ASH

The replacement of Portland cement by class F fly ash (ASTM C 618), was found to reduce the rate of slump loss in a prolonged mixed concrete, and this reduction increased with the

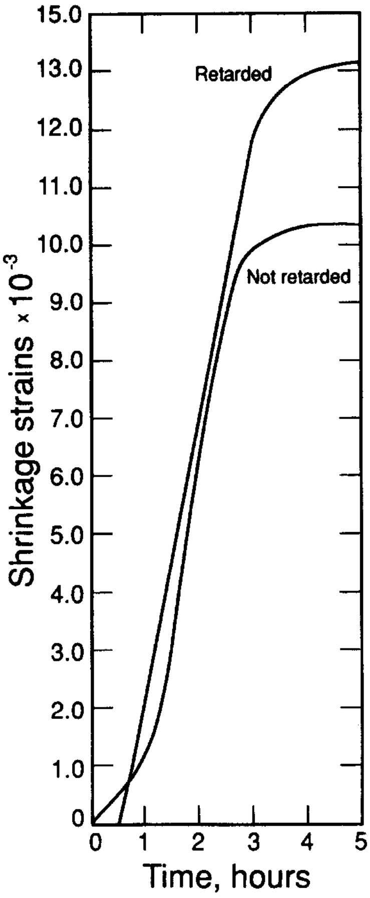

Fig. 6. Plastic shrinkage of retarded and unretarded cement mortars of plastic consistence and OPC content of 550 kg/m^3. Air temperature 30°C, wind velocity of 20 km/h and infra-red irradiation. After Ravina and Shalon.[18]

increase in the amount of the cement replaced (Fig. 7). This effect cannot be attributed to the resulting lower cement content and the associated lower heat of hydration, because replacing the cement by identical amounts of fine sand, hardly affected slump loss. That is, the use of fly ash as such brought about the reduction in the rate of slump loss.

Moreover, the reducing effect of fly ash on the rate of slump loss has been demonstrated again lately in concrete mixes in which the fly ash replaced the fine sand and not the cement (Fig. 8). It is clearly evident that incorporating fly ash in the mix considerably reduced the rate of slump loss, and this reduction was more than enough to overcome the accelerating effect of the rise in temperature from 21°C to 32°C.

The effect of fly ash on reducing slump loss can be attributed to chemical and physical factors. It was found[21,22] that the surface of fly ash particles may be partly covered with a vapor-deposited alkali sulfate that is readily soluble. Thus, the early hydration process of Portland cement is effected because sulfate ions have a retarding effect on the formation of the aluminates. Indeed, fly ash was found[23] to be a more effective retarder than an equivalent quantity of gypsum. It seems that because the solubility of gypsum in water is low, it limits the amount of sulfate ions that go into solution, which allows the sulfate from the fly ash to be available for quite a long time to retard the hydation process of the C_3A.

Fly ash also was found to be beneficial in reducing slump loss in concretes with conventional water-reducing and retarding admixtures.[24] The effect of the retarding admixtures was essentially the same as the previously discussed effect, namely such admixtures accelerated, rather than slowed down, the rate of slump loss. Moreover, this accelerating effect took place also in the concrete mixes in which fly ash was used. Nevertheless, in mixes where both fly ash and admixtures were used, the rate of slump loss remained much lower than the rate in mixes containing no fly ash and, again, this reduction was more than enough to counteract the adverse effect of the elevated temperature of 32°C. It was pointed out earlier that retarders, although accelerating the rate of slump loss, may prove beneficial under hot weather conditions, because of their effect on water demand, possible formation of cold joints, etc. Noting that the presence of fly ash in the concrete mix may counteract the adverse effect on the rate of slump loss of both temperature and retarders, it may be concluded that, under hot weather conditions, the combined use of class F fly ash and retarders, is to be recommended. However, it must be realised that similarly to the effect of retarders, the use of fly ash involves greater plastic shrinkage[25] and thereby increases the vulnerability of the concrete to plastic shrinkage cracking. Hence, when fly ash is used, and particularly when combined with WRR admixtures, extra care should be taken in order to prevent such cracking by protecting the fresh concrete from drying as soon as possible after being placed and finished.

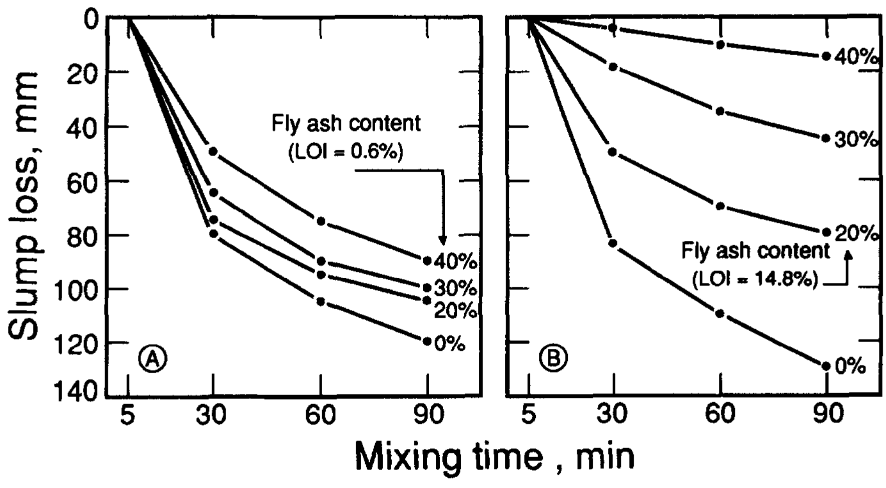

Fig. 7. Effect of replacing the cement with class F fly ash (ASTM C 618) on the rate of slump loss at 30°C. Loss of ignition of fly ash A and B is 0.6% and 14.8%, respectively. After Ravina.[20]

CONCLUSIONS

The use of water reducing and retarding admixtures (i.e. type D in accordance with ASTM C 494) in concrete subjected to prolonged mixing (ready-mixed concrete) accelerates, rather than slows, the rate of slump loss. This effect, which may not be observed in all possible combinations of retarders and OPC cements, must be considered, however, as a distinct possibility. Nevertheless, such admixtures may be used when prolonged mixing is involved, provided they are mainly utilised to reduce water demand and delay setting.

The use of retarding admixtures increases plastic shrinkage and reduces early tensile strength development. Accordingly, such use increases the likelihood of plastic shrinkage cracking to occur. Hence, when type D admixtures are used, extra care should be taken to protect the retarded fresh concrete from drying as soon as possible, and particularly under hot and dry weather conditions.

It was found that utilization of class F fly ash for replacing part of Portland cement, or part of the fine sand, may reduce the rate of slump loss in prolonged mixed concrete. It is concluded that, under hot weather conditions, the combined use of class F fly ash and retarders is to be recommended. It must be realised, however, that similar to the effect of retarders, the use of fly ash involves greater plastic shrinkage[25], and the vulnerability of the concrete to plastic shrinkage cracking is therefore increased. Hence, when fly ash is used, extra care should be taken in order to prevent such cracking by protecting the fresh concrete from drying as soon as possible after being placed and finished.

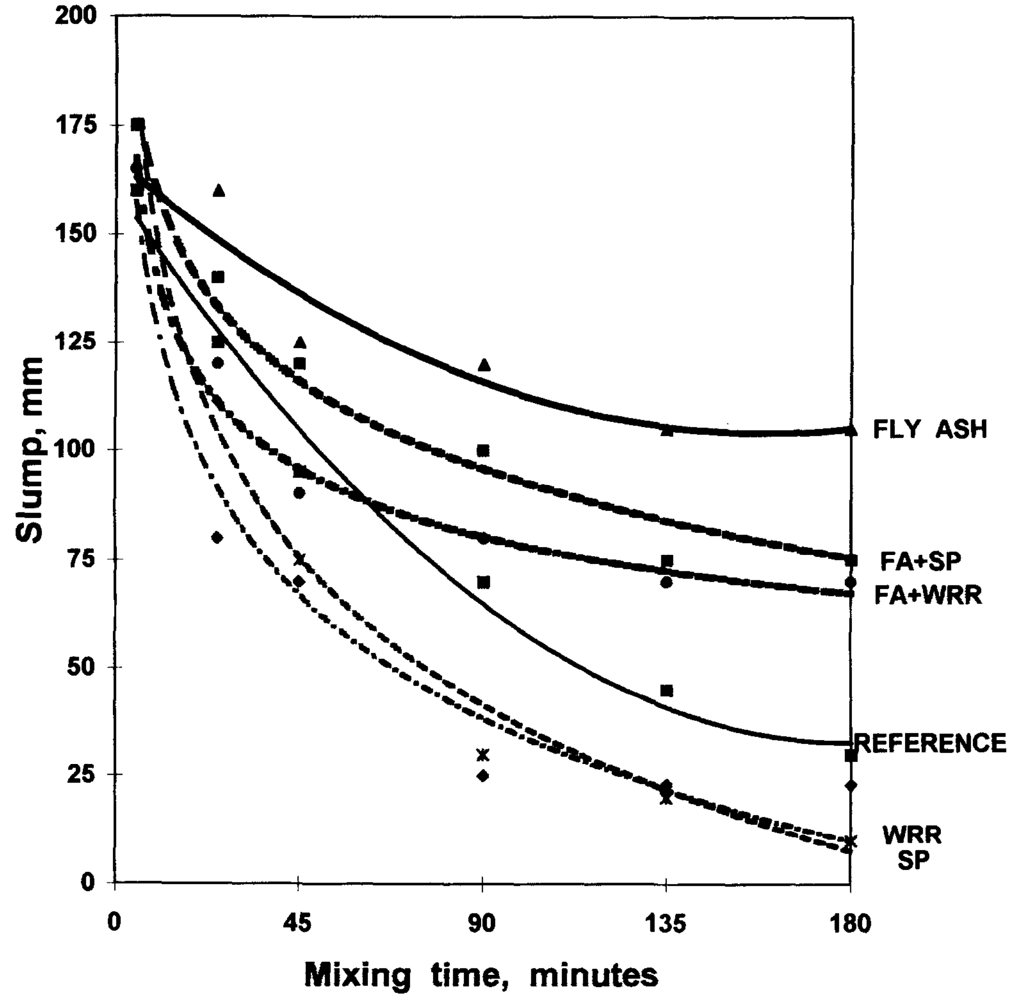

Fig. 8. Slump loss of concretes with and without fly ash and with and without a water-reducing and retarding admixture or a superplasticizer after prolonged mixing at 32°C (90°F). After Ravina.[24]

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