Suitability of GGBFS as a cement replacement for concrete in hot arid climates

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Three ground granulated blast-furnace slag (GGBFS) concretes (30, 50 and 70% cement replacement) together with an OPC control, all designed for equal workability and 28-day water-cured strength, are compared when subjected to a variety of curing methods and exposure in both a temperate and a hot arid climate. The effect of replacement level on cube and core strengths, ultrasonic pulse velocity, surface hardness, water absorption and permeability are reported. The tests showed conclusively that the 50% replacement level was best and that a GGBFS concrete can be superior to an equivalent all-OPC concrete in a hot climate, provided that proper curing is provided.

1. INTRODUCTION

Producing strong and durable concrete in a hot arid climate can be considerably more difficult than in a temperate one. This has led to an interest in suitable curing methods and alternative cementitious materials to improve concrete quality in hot countries. At Loughborough we have been investigating the use of cement replacements in hot climates [1,2], concentrating on curing methods, replacement levels and durability-related properties as well as strengths. To simulate concreting in hot conditions, freshly cast specimens were placed in a climatic room for up to 180 days (28 days for the study of ground granulated blast-furnace slag (GGBFS)), where the temperature and humidity were varied over a 24-hour cycle period to simulate a particular hot arid climate (for example Africa or the Middle East).

The work on GGBFS has examined the effect of a variety of curing methods on the development of strength and permeability [3], together with the effects of cement replacement level and specimen type which are reported in this paper. All our work has compared OPC and OPC-modified mixes designed to have equal workability and 28-day strength when cured under water at 20°C; this is in contrast to the practice of simple weight-for-weight replacement which makes direct comparison of performances less meaningful. Duplicate samples have also been conditioned in the temperate climate of the laboratory to identify the relative efficiencies of the replacement materials in the different climates.

2. CONCRETING IN HOT CLIMATES

Hot weather introduces many problems in manufacturing, placing and curing concrete that can adversely affect the properties and serviceability of the hardened concrete which cannot be rectified later. Climatic conditions typical of North Africa [4] and the Middle East [5] are given in Table 1. In hot arid countries, the temperature often rises above 40°C in the shade, mainly during the months of May, June, July and August. The mean maximum temperature in the summer day time can be 25°C. Thus a variation in the ambient temperature of 20°C within 24 h is typical and can be as much as 30°C. This, when combined with prolonged exposure to direct sunlight, can cause several problems. The rate of water evaporation increases as the air temperature increases; for example, an increase from 10 to 20°C will result in the doubling of the rate of evaporation from the concrete [6]. High ambient temperatures can also raise the temperature of concrete ingredients to an unacceptable level; on mixing, the concrete temperature will be high enough to cause rapid stiffening which prevents satisfactory compaction and can result in a porous permeable concrete. High ambient temperature increases the rate of surface evaporation which may lead to plastic shrinkage cracking.

In addition to ambient temperature, other climatic factors occur in varying combinations which also need to be taken into account in order to assess the severity of the effects of weather conditions on concrete. These factors are: wind velocity, relative humidity, and to a lesser extent precipitation and solar radiation. Substantial changes in air temperature are accompanied by large changes in relative humidity, which, in turn, are influenced by location (proximity to the sea) and by the direction of wind. A decrease in relative humidity from 90 to 50% without change in any other condition, will increase fivefold the rate of evaporation of water from the exposed surfaces [6].

The rate of air movement is probably the factor which does most to create the problems associated with concreting in hot dry weather. The rate of evaporation increases substantially in windy conditions, and can reach serious proportions if wind speeds exceed 15 km h⁻¹. For
Table 1 Typical climatic data for the central regions of Algeria [4] and Iraq [5]

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<th>Average daily temperature (°C)</th>
<th>Average RH (%) at 0600 hours</th>
<th>Average RH (%) at 1200 hours</th>
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instance, in a breeze of 15 km h⁻¹, water evaporates at about four times the rate in still air; in a wind of 40 km h⁻¹ the rate can be increased up to nine times that in still air. With the three adverse factors, high air temperature, reduced relative humidity and high wind velocity present simultaneously, it is very difficult to keep the surface of fresh or immature concrete in a moist condition. This is one of the most important and fundamental problems to be overcome, because desication of concrete as a result of rapid loss of water can seriously impair its durability, particularly if this moisture loss occurs at a very early stage.

The strength and durability of GGBFS concrete, and in particular its resistance to penetration by liquids, gases and ions, are highly susceptible to curing conditions. This susceptibility can be attributed to reduced formation of hydrates at early ages, leading to increased loss of moisture which would otherwise be available for hydration to continue. GGBFS concretes can therefore be expected to need longer curing periods where durability is recognized as a potential problem. For instance, BS 8110 [7] recommends longer periods of curing for GGBFS concretes in hot conditions and where the surface is exposed to sun and wind. For cement-rich OPC concrete, a substantial rise in temperature during the early stages of hardening has adverse effects on the strength and the durability at later ages. The strength and permeability of GGBFS concrete have been reported [8,9] to be less adversely affected and may even benefit from increased temperature provided that good curing is applied. However, CIRIA [10] noted in 1984 that there had been no systematic evaluation of the performance and specific requirements of concrete made with GGBFS in the Gulf region, and concluded that field trials and laboratory tests were needed for this purpose; such studies would allow better specification of concrete and concreting operations.

Various studies, including that of Graf and Grube [11], have reported that GGBFS concrete can have lower permeability than an equivalent OPC concrete with good curing, but a higher permeability when curing is poor. It has also been reported [12] that as the GGBFS content is increased, the permeability of concrete decreases. This is the result of the pore refinement of the cementitious matrix through the reaction of GGBFS with the calcium hydroxide and alkalis released during the hydration of the Portland cement. Gowripalan et al. [13] have recently reviewed the effect of curing on porosity, permeability and water absorption of GGBFS concrete and found that at 70% replacement it had a lower porosity when cured at 35°C than when cured at 21°C; this illustrates a potential advantage of using cement replacements in hot climates.

3. EXPERIMENTAL PROCEDURES

3.1 Materials and mix proportions

The cement used throughout the test programme was ordinary Portland cement supplied by Castle cement, conforming to the requirements of BS 12 [14]. The slag conformed to BS 6699 [15], and was supplied by the Blue Circle Group from its Rouse works near Cardiff. Its chemical composition is shown in Table 2. The