The effect of heat treatment on the compressive strength of cement-slag mortars

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Temperature variation caused by the heat of hydration in mass concrete or the change of external environment, has a considerable influence on the mechanical properties of early-age concrete. Mechanical properties such as compressive strength are factors to be considered in the design and construction of concrete structures. Therefore, the effects of temperature and aging on the mechanical properties should be studied and quantified. According to the experimental results, concrete subjected to high temperatures at early ages attains higher early-age compressive and splitting tensile strengths but has lower later-age compressive and splitting tensile strengths than concrete subjected to normal temperatures [1]. Mortar and concrete are the most important elements of structures and, if well-designed, can be durable construction materials. One effective way to reduce the environmental impact is to use mineral admixtures as a partial cement replacement. This strategy has the potential to reduce costs, conserve energy, and reduce the volume of waste. Mineral admixtures are silica-based materials such as ground granulated blast furnace slag (GGBFS), fly ash, and silica fume. Mineral admixtures are being used more and more for concrete because of their strength and durability [2]. The presence of some mineral admixtures such as GGBFS in the cement, can modify the kinetics of hydration, reduce the heat evolution, and produce additional calcium silicate hydrates (C–S–H) gel. These admixtures result in a noticeable performance increase in the concrete in hot climates as the negative effect of the temperature is partly reduced by the pozzolanic reaction, their weak hydration heat, and their great activation energy.

The use of pozzolans as supplementary cementing materials has been found to provide noticeable enhancement to the mechanical properties of concrete and mitigate the damage, which is of particular concern for durability. Based on various studies on the effects of heat curing on cementitious systems, heat treatment of concrete has become a regulated practice in the precast concrete industry. In the 1980s Germany introduced heat curing regulatory particles specifying the parameters of the curing cycle including a maximum temperature of 60 _C. Presently, certain countries including Canada, the United States, South Africa, and most European countries have developed similar specifications for the regulation of heat curing for precast concrete. The maximum curing temperature imposed is often 60–70 _C. The length of heat exposure is not usually included in these specifications as this can be adjusted without adversely affecting performance [3]. Several researchers [1,2,4–6] reported that a high temperature improves strength at early ages. At a later age, the important numbers of formed hydrates have no time to arrange suitably and this causes a loss of ultimate strength; this behaviour has been called the crossover effect [7,8]. For ordinary Portland cement (OPC), it appears that the ultimate strength decreases with curing temperature nearly linearly [9]. Since GGBFS itself is nothing more than a latent hydraulic binder, it must be activated to react and provide the desirable mechanical properties. One of these activation methods is the thermal method [10]. The objective of this study is to produce a data inventory of the early-age behaviour of some mechanical properties, such as the compressive strength of mortars with temperature, as well as to investigate the relationship between compressive strength with temperature and the relationship between the compressive strength of specimens cured in air under room temperature and water at 3 and 7 days, for 40% and 50% levels of replacement slag.

Experimental procedure

Mix proportions and curing

Table 1 represents the mix proportions for different mortars. In all the mixes w/b = 0.33, s/b = 2.25. Silica sand was used in the mixes. At first, based on grain size distribution, five grades of silica sand were mixed. Two minutes after that cement and replacement slag were put into the mixture, followed by four minutes of mixing.

Notes: OM = OPC mortar, OSM/i = OPC _ slag mortar for i% replacement with slag.

Mixing water was then added to the mix, and mixing was continued for two minutes, after which the required amount of super plasticizer was added. Mixing was continued for two minutes; finally, the moulds were filled with fresh mortar in two layers. Each layer was compacted with ten impacts by a rod of 16 mm diameter. The specimens were demoulded 24 h after casting and heated in water at 60 _C for the required time as mentioned in Table 1, and then cured in air under room temperature 28 ± 4 _C with 70 ± 10% relative humidity and water with 23 ± 3 _C until the test day.

Properties of materials

Cement

The cement used in all the mixes was OPC. ASTM C109-99 [11] was used for the determination of the compressive strength of hydraulic cement mortars using 50 mm specimen cubes. The specific gravity of the cement used was about 3.14. Based on particle size analysis tests, the specific surface area (SSA) for OPC particles was determined to be 1.8939 m^2/g. The chemical composition of the OPC used in this study was determined by the X-ray fluorescence spectrometry (XRF) test, as given in Table 2.

Slag

The specific gravity of slag was approximately 2.87, with its bulk density varying between 1180 and 1250 kg/m^3. The colour of GGBFS is normally whitish (off-white). Based on the results of the particle size analysis test, the SSA for GGBFS was determined to be 3.5972 m^2/g. It can be seen that SSA slag is 1.9 times of SSA OPC, which means that the particles of slag are 90% finer than those of OPC. The composition of slag is given in Table 2. As with all cementing materials, the reactivity of the slag is determined by its SSA. In general, increased fineness results in better strength development, however, in practice; fineness is limited by economics, performance considerations and factors such as setting time and shrinkage [12]. For better performance, the fineness of GGBFS must be greater than that of OPC. Based on the definition of the slag activity index (SAI) in ASTM C989 [13], it can be seen that SAI = (SP/P) _ 100; where SP = average compressive strength of slag-reference cement mortar cubes and P = average compressive strength of reference cement mortar cubes. Based on this definition, the slag used in the tests is classified into Grade 120. A sample calculation is shown in the bottom of Table 2 [14].

Aggregates

The fine aggregate used in the mixes is graded silica sand with specific gravity, fineness modulus, and water absorption 2.68%, 3.88%, and 0.93%, respectively. The maximum aggregate size is 4.75 mm. The grain size distribution of the fine aggregate is given in Table 3 and the grain size distribution diagram is shown in Fig. 1 [15].

Super plasticizer

In order to have a proper consistency with a low w/b ratio, super plasticizer is required. The specific gravity of super plasticizer is approximately 1.195, is dark brown in colour, with a pH in the range of 6–9. The consumed amount of super plasticizer in the mortar depends on the replacement level of slag. It is a chloride-free product that meets ASTM C494 [16]. The basic components are synthetic polymers, which allow the mixing water to be reduced considerably. The dosage of super plasticizer generally varies from 0.8 to 1.2 litre/(100 kg) of cement. Other dosages may be recommended in special cases according to specific job conditions. It is compatible with all cements and admixtures meeting ASTM and UNI standards.

Water

The water used in all the mixes and curing of the specimens was potable water.

Test and mixing procedures

Test for fresh mortar

In order to have appropriate consistency for each mortar, after casting, a flow table test ASTM C230/C230M-08 [17] was performed. The range of flow amounts were 220–235 mm. First, some mortar was put in the truncated brass cone in two layers and each layer was compacted 10 times by a steel rod of 16 mm diameter. The cone was then lifted and the mortar was collapsed on the flow table. Following that, both the table and mortar were jolted 15 times in a period of 60 s. The jolting of the table, allowed the mortar to spread out and the maximum spread to the two edges of the table was recorded. The average of both records was calculated as flow in mm.

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