

# Relationships between compressive strength of cement-slag mortars under air and water curing regimes

Fathollah Sajedi , Hashim Abdul Razak , Hilmi Bin Mahmud , Payam Shafigh

Ground granulated blast-furnace slag (GGBFS) is commonly used in combination with Portland cement in concrete for many applications. Concrete made with GGBFS has many advantages, including improved durability, workability and economic benefits. The drawback in the use of GGBFS concrete is that its strength development is considerably slower under standard 20 °C curing conditions than that of Portland cement concrete, although the ultimate strength is higher for the same water-binder ratio. GGBFS is not therefore used in applications where high early age strength is required [1].

The use of GGBFS in mortar has increased in recent years. Records indicate that blast furnace cement was used for the mortar during the construction of the Empire State Building in the 1930s. These materials not only impart technical benefits to both the fresh and hardened properties of mortar they are also environmentally friendly. GGBFS is classified as a latent hydraulic material. This means that it has inherent cementitious properties, but these have to be activated. The normal means of achieving this is to combine the material with Portland cement [2].

Slag cement has been used in different concrete projects of the United States of America for the last several decades. Besides, earlier usage of slag cement in Europe and elsewhere demonstrate the long term performance of slag concrete in many ways. Use of slag is noticeably increasing for the last several years due to its characteristic properties like improved workability, restrained heat of hydration, easier finishability, higher compressive strength, lower permeability and superior resistance to alkali silica reaction due to penetration of chloride ions and sulfate ions. It has been observed that slag can be effectively used to reduce the pore sizes and cumulative pore volume considerably leading to more durable and impermeable concrete. Although the strength development is remarkably reduced at early ages of curing due to having low initial rate of hydration of slag, the structural benefit of low heat of hydration of slag in decreasing the thermal cracking of mass concrete is significant. The risk of thermal cracking in slag concrete

is seen to be lower than ordinary Portland cement. In Europe, the production of 1 ton OPC generates about 1.2 ton CO<sub>2</sub> while the production of 1 ton slag generates only 0.45 ton of CO<sub>2</sub>. In addition, concrete made with slag has a lower content of chromium, which is responsible for skin irritation of workers handling concrete materials without any skin protection [3].

From both environmental and economical points of view, blast furnace slag is a very attractive mineral admixture to use in concrete, particularly in low-heat concrete for massive structures or in high performance concrete. Apart from the low-heat application, the superior durability of GGBFS against aggressive environments

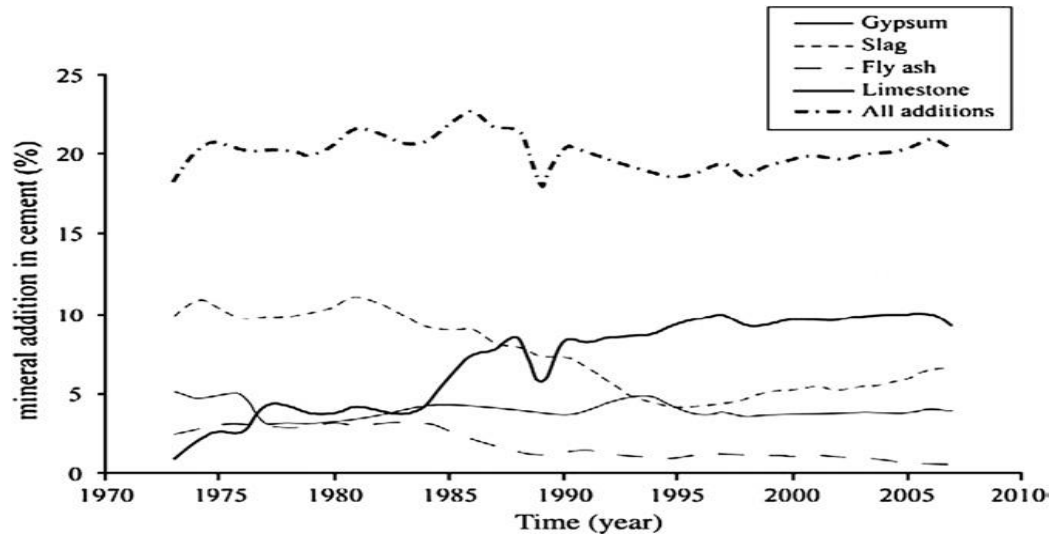


Fig. 1. Evolution of clinker substitution from 1973 to 2007 [14].

In all the mixes  $s/b = 2.25$  and  $w/b = 0.33$  were used; total water = free water + absorbed water by fine aggregates; absorption content for silica sands was used as 0.93%; all the specimens were cured in curing regimes ac and wc after casting and demoulding.

**Notes:** GGBFS = ground granulated blast furnace slag, OPC = ordinary Portland cement, SP = super plasticizer, OM = OPC mortar, OSM = OPC-slag mortar, SM = slag mortar, ac = air curing under room temperature, wc = water curing.

makes this cement a suitable binder for concrete exposed to chloride, acid, and sulphate attacks. However, one of the disadvantages of GGBFS concrete is its poor resistance against carbonation. After carbonation attack, GGBFS concrete is vulnerable to scaling under the combined load of freezing-thawing and de-icing salt. Owing to surface disintegration, other attacks on the structure are more likely which can result in a dramatic decrease in durability [4]. Global cement production is expected to increase 2.5 times between 2005 and 2050 with the majority of this growth occurring in developing countries. The consolidated strategies to reduce CO<sub>2</sub> emissions resulting from the production of clinker are as: the substitution

of clinker by mineral admixtures like blast-furnace slag, the use of alternative fuels such as bio-fuels and waste and increasing energy efficiency of the production process. Another strategy for reducing CO<sub>2</sub> emissions is to improve the efficiency of cement use [5-8]. Slag-based blended cements are now marketable worldwide and slag has been incorporated in quantities up to 85% by weight in different mix designs [9]. GGBFS is a by-product of the iron making process and is produced by water quenching molten blast furnace slag. Use of GGBFS as a cement replacement in mortar and concrete is a common practice due to technological and environmental benefits. A lower cost and lower environmental impact, per unit volume, its application can perform similar properties of concrete as compared to ones with pure Portland cements [10]. Replacement of clinker by slag not only offers energy savings and cost reduction compared to ordinary Portland cement (OPC), but also has other advantages such as low heat of hydration, high sulfate and acid resistance, better workability, and good ultimate strength and durability [11]. GGBFS is commonly used in combination with Portland cement in concrete for many applications [12,13].

Fig. 1 presents the evolution of mineral addition in cement from 1973 to 2007. It shows that the percentage has remained roughly constant at about 20% over the last 30 years, but its nature has changed with a diminution of GGBFS and an increase in limestone addition. This can be associated with the decline in French steel industry that began in the late 1970s, coupled with changes in standards that permitted higher level of limestone addition. It has to be noted that such substitutions are not made exclusively during cement production; they can also be made during concrete production [14].

Concrete made with GGBFS has many advantages, including improved durability, workability and economic benefits [12]. The drawback in the use of GGBFS concrete is that its strength development is considerably slower under standard 20 °C curing conditions than that of Portland cement concrete, although the ultimate strength is higher for the same water-binder ratio [15,16].

As reported in [17], the mortars used in this study can also be classified into three groups as OPC mortars (OMs), OPC-slag mortars (OSMs) and slag mortars (SMs). Three groups of mortars were made in this experimental work. In the first group, only OPC was used as binder. In the second group, both OPC and GGBFS were used. Finally, in the third group, GGBFS was only used. The results

obtained showed that the second group of mortars gave the highest strengths when the specimens were cured in water in duration up to 90 days.

As reported by the researchers [18] ‘ ‘If the potential of concrete with regards to strength and durability is to be fully realized, it is mostly essential to be cured adequately. The curing becomes even more important if the concrete contains supplementary cementing materials such as fly ash or ground granulated blast-furnace slag or silica fume, and is subjected to hot and dry environments immediately after casting’ ’. Curing of concrete is maintaining satisfactory moisture content in concrete during its early stages in order to develop the desired properties. However, good curing is not always practical in many cases. Curing of concrete plays a major role in developing the concrete microstructure and pore structure, and hence improves its durability and performance, i. e. each 1 m<sup>3</sup> of concrete requires about 3 m<sup>3</sup> of water for construction most of which is for curing [19]. groups of mortars for binder contents 380 and 500 kg/m<sup>3</sup> in different curing regimes ac, wc were analyzed in duration up to 90 days. Variations of compressive strengths for all three groups of mortars having binder contents 380 and 500 kg/m<sup>3</sup> are shown in Figs. 3-5. One of the findings in this study is to use both slag and OPC to achieve the highest compressive strength for OPC-slag mortars. This was found OSM380-wc about 80 MPa at 90 days with use of only 190 kg/m<sup>3</sup> cement content in one meter cube of mortar.

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