Effects of slag and fly ash in concrete in chloride environment

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Key note lecture presented at Durability aspects of fly ash and slag in concrete, Nordic Workshop, February 15-16, 2012, Oslo, Norwegian Public Roads Administration

EXTENDED ABSTRACT

This paper addresses experience from The Netherlands with blast furnace slag and fly ash in concrete in chloride contaminated environments, both from the field and the laboratory. Use of slag produced in The Netherlands started in the 1930s and CEM III/B LH HS, with typically 70% slag, became the dominant cement type in the 1970s. Approximately 10 million cubic metres of slag cement concrete are produced annually, in particular for concrete cast in situ. The low heat of hydration is seen as a big advantage. Fly ash has been used since the 1980s at typically 27% replacement level. Traditionally slag and fly ash were intermixed with clinker in the cement plant and sold as “cements”. The manufacturer would carefully compose these products to have similar 28 day strength as Portland cement, typically 32.5 or 42.5 MPa. In the 1990s CEM III/A 52.5R was introduced, with 52-57% slag, aimed at the precast industry. Recently, separate slag for addition to Portland cement in the concrete mixing plant has become available. Traditional concrete technology for aggressive environments involves about 340 kg cement per cubic meter, a w/c of 0.43 and rounded siliceous aggregate of 32 mm maximum size.

A lot of independent research has been devoted to slag cement in concrete and its durability over the last 40 years, both in the field and in the laboratory. Here the focus is on research in The Netherlands. In the 1970s durability was investigated of structures in marine environment [1]. Slag cement concrete appeared to perform very well, with hardly any visible corrosion in about 50 structures up to 40 years of age. Exposure for 16 years of concrete prisms submerged in the North Sea showed that slag cement had much lower chloride penetration than Portland cement concrete [2]. An overview was published including examples of slag in structures in the Middle East, underpinning its durability [3]. In depth investigation in the early 2000s of six marine structures of up to 40 years age showed that chloride penetration was consistently slow in slag structures [4]. This study also narrowed the gap between field work and laboratory tests. In the laboratory, various durability and corrosion related properties had been investigated since the 1980s, including electrical resistivity [5] and its relationship to chloride transport [6], corrosion rates with mixed in chloride [7] or penetrated chloride [8]. Slag cement concrete was shown to have higher electrical resistivity and lower corrosion rates than Portland cement concrete under comparable conditions. Diffusion testing was carried out for various blended binder concretes, including slag and fly ash/silica fume mixes [9]. In the meantime, a practical accelerated test method for chloride penetration was developed in Scandinavia, NTBuild 492

[10, 11, 12]. A method for quality control based on resistivity was proposed [13]. Parallel development of probabilistic service life modelling will not be addressed here [13]. With service life modelling as the objective, questions regarding the critical chloride content arose. The case for slag concrete has not been clarified completely, but present limited information suggests it appears that critical chloride levels are similar as in Portland cement concrete [14, 15]. Further work is underway. A concern for slag may be its early hydration, as a more porous microstructure at early age may be a disadvantage when the concrete is exposed to chloride from say a few days age on. Recent work has clarified this issue: it appears that up to seven days the diffusion coefficient for chloride is higher than for Portland cement, but from then on progressively becomes much lower. Modelling has shown that the effect of exposure to chloride at one day age after versus starting at 28 days for a total exposure period of 50 years is very small [16]. Chloride penetration is still much lower than for Portland cement in a comparable situation. A relative weakness of slag is its higher sensitivity to poor curing [17]. Finally, research underpinning a recent Technical Recommendation for service life design in XS/XD environments has shown that the dependency of the chloride diffusion coefficient on w/c is much smaller than for Portland cement [18, 19]. This implies that small deviations from the target w/c have a small effect in slag cement concrete, making it more tolerable for production related fluctuations.

Research on fly ash parallel to that mentioned for slag has been conducted in The Netherlands since the 1990s. For typical fly ash replacement levels of about 27%, high resistivities and low corrosion rates were found [8]. Chloride diffusion may be relatively high at 28 days, but progressively becomes much lower over say up to one year, approaching that of slag cement. Fly ash hydration is apparently slower than slag hydration, requiring up to several months to fully develop its beneficial effects, including high resistivity [8, 20]. Fly ash diffusion coefficient dependency on w/c is intermediate between slag and Portland cement [18, 19]. A recent study exploring extremely low clinker contents showed that with 250 kg “binder” per cubic meter and 30 to 70% fly ash of total binder, relatively low diffusion coefficients could be obtained at one year age [21]. Such concretes, however, are very sensitive to curing, as they carbonate rather quickly and show increased freeze-thaw damage if not hydrated properly, that is, by long wet curing.

Although studied much less, Dutch work on blends of slag and fly ash and of fly ash and silica fume may provide additional data. So-called composite cements, CEM V/A, containing slag and fly ash up to a total of 50% were found to produce low diffusion coefficients and high resistivity [8, 20]. In the 1990s a mix with 10% fly ash and 5% silica fume was studied for chloride diffusion and resistivity: it produced low diffusion and high resistivity values [6, 9]. It approached the behaviour of classic slag cement concrete. In these respects, it performed particularly better than a mix with 5% silica fume (to Portland cement) only.

Summarising, replacement of clinker by slag at high levels and fly ash at intermediate levels produces high chloride penetration resistance and high electrical resistivity, overall decreasing the risk of corrosion in chloride contaminated environments. The need for sufficiently long wet curing is the main concern with slag and in particular fly ash based blended binders.

Key words: durability, concrete, chloride, corrosion, diffusion, resistivity, blast furnace slag, fly ash

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