Abstract

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Title: The Role of Reactive MgO as an Expansive Additive in the Shrinkage Reduction of Concrete

Hard-burnt magnesium oxide (MgO) has been successfully used in large volume concrete, mainly dam construction in China, for thermal shrinkage reduction since the 1970's. At ~4% addition to the cement by weight, it is much simpler than conventional shrinkage measures and in particular, reduces the quantity of crack control reinforcement used. The mechanism is similar to conventional ettringite-based and lime-based expansive admixture relying on their expansion to offset concrete shrinkage. In other words, the tensile stresses induced by concrete shrinkage are offset by the compressive stresses induced by MgO expansion under a restrained condition so that shrinkage and cracking can be reduced. While there are technical specifications in China for this application, the production of MgO is not robust enough to produce specified MgOs, and thus specific performance cannot be specified or guaranteed. In addition, there has been very little rigorous scientific research work in the literature on the performance mechanisms and controlling variables. These issues have hindered the application of the unique designable expansion characteristics of MgO and have limited the application in thermal shrinkage reduction. Hence, this PhD study aims to investigate the expansive characteristics of a number of commercially available MgOs used as an additive and evaluate their shrinkage reduction in cement and concrete. This work also presents a literature review of MgOs, particularly from Chinese sources, and a thorough evaluation of the expansion characteristics and shrinkage reduction capabilities of MgOs with different reactivities in both cement paste and concrete.

To this end, four different reactivity MgOs obtained from seawater, brine and magnesite were tested. First, cement paste and concrete prisms - both cured in water - were used for correlating MgO reactivities with expansion characteristics under unrestrained and restrained conditions. The changes in length in cement paste and concrete prisms showed that the MgO expansion rate and magnitude increased with MgO content and reactivity as well as water content. Provision of restraint in prisms both decreased the magnitude and rate of expansion. Highly reactive MgOs showed higher early age expansion and plateaued in a relatively short period while less reactive MgOs exhibited delayed expansion. Temperature increase accelerated all MgOs hydration activation. In particular, less reactive MgOs displayed rapid expansion at an early age instead of delayed expansion. With regards to unrestrained compressive strength

development, it was found that the higher the MgO expansion, the greater the compressive strength reduction. Microstructural analyses confirmed the existence of MgO hydration product brucite which contributed to the expansion. While the brucite quantity increased in cement paste systems, it had an insignificant influence on cement paste pH and thus potential reinforcement corrosion resistance. Similar expansion characteristic was found in the PC-Slag cement pastes containing different reactivities of MgOs as compared to that of PC cement paste except that the PC-Slag cement pastes displayed a slightly higher expansion than PC cement at an early age but lower ultimate expansion.

One high reactivity MgO (MgO-N50) and one medium reactivity MgO (MgO-92/200), with distinct expansion characteristics, were selected for evaluating the shrinkage reduction performance of cement paste in autogenous and drying curing conditions. Autogenous shrinkage of unrestrained cement paste prisms was measured using laser sensors and length comparator at an early age (<24 hours) and long-term respectively. The results showed that autogenous shrinkage in the cement paste containing the MgOs was reduced and further decreased with MgO reactivity, content, as well as water content. Compared to PC, the slower strength development in PC-Slag cement resulted in smaller autogenous shrinkage reduction. Drying shrinkage reduction was observed at an early age in both PC and PC-Slag unrestrained cement paste containing the MgOs at water-to-bonder (w/b) ratio of 0.5, although the long-term shrinkage was higher than the control.

To further investigate the benefit of early age MgO expansion in drying shrinkage reduction, the final part of the study focused on restrained concrete specimens using the restrained ring test. The results showed that drying shrinkage was reduced in PC concrete with the addition of the highly reactive MgO-N50 when the w/b ratio was increased from 0.40 and 0.50. On the contrary, drying shrinkage reduction was not observed in the PC concrete with the less reactive MgO-92/200. Neither MgOs in PC-Slag concrete showed drying shrinkage reduction. The results reaffirmed the earlier findings that MgO expansion is dependent on strength development. The combination of pre-compressive stresses, delay in tensile stress development and smaller modulus of elasticity of MgO concrete contributed to a lower stresses-to-strength ratio and thus higher resistance to cracking caused by drying shrinkage. From an engineering point of view, the high reactivity MgO-N50 characterised by early age expansion can be used for reducing concrete autogenous shrinkage as it is used for drying shrinkage effect. The less reactive MgO-92/200 with delayed expansion can be utilised in mass concrete to address thermal shrinkage.