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EDITORIAL

Development of Low-carbon and Sustainable Magnesium-bearing Cementitious Materials-based Solidification Approaches for Management of Problematic Soils

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ABSTRACT

The production of traditional cementitious binders such as calcium-based Portland cement poses a serious challenge to the environment and society. Therefore, low-carbon, green and sustainable magnesium-based cementitious materials are developed to replace fully or partly Portland cement and reduce the consumption of natural resources and CO_2 emissions. Three interesting techniques, including reactive MgO-activated industrial solid wastes, MgO-based cement and carbonation of magnesium-bearing materials, are elucidated to point to the necessity for developing novel magnesium-based cementitious materials. In the coming future, the carbonation of magnesium-rich industrial solid wastes or its combination with reactive MgO for application in various construction sectors such as soft ground improvement and concrete fabrication would be a promising approach to generate high-value products based on industrial solid wastes.

Keywords: Mg-bearing binder; Solidification; Soil; Carbonation

The uninterrupted population growth and economic development would unavoidably require more living space and infrastructure construction, especially in the coastal, lake, valley and river regions. In these areas, soft soils with high water content, high compressibility, low bearing capacity and low strength pose a serious challenge that must be addressed before the infrastructure construction. To overcome efficiently the intractable issue, a commonly accepted approach—Portland cement-based solidification

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method is being developed and attracting more and more attention worldwide [1-4]. However, in general, producing 1 ton of traditional Portland cement must generate 0.94 tons of CO_2 (0.55 tons of chemical CO_2, 0.39 tons of CO_2 from fuel emissions) [4,5]. The quantity of CO_2 emitted from the cement industry has been estimated to be about 5%-7% of the world's total CO_2 emissions [6]. Consequently, developing low-carbon, sustainable and high-efficiency binders for the solidification of problematic soils is an important and promising issue that deserves to be probed to replace partly or fully calcium-based Portland cement.

The magnesite deposit in China is an abundant reserve that occupies the first place in the world. It provides a great opportunity to synthesize magnesium-bearing cementitious materials, which are generated at lower calcination temperatures and less energy and resource consumption in contrast with Portland cement. For soil solidification, reactive MgO has been incorporated to activate the pozzolanic properties of industrial solid wastes such as granulated blast furnace slag and fly ash [7,8], generating C-S-H or M-S-H gels at high alkalinity that are essentially the micromechanisms for soil improvement. In fact, the incorporated MgO plays a duel role in the process of MgO activated industrial solid wastes: (i) Similar to lime (CaO), MgO dissolves in water to form brucite ($Mg(OH)_2$) that fills into pore space and cements fines grains together, and (ii) MgO reacts with active components (SiO_2) contained in solid wastes in the presence of water to produce M-S-H or provides an alkaline environment to facilitate the production of C-S-H gels. Nevertheless, it is observed that the strength development is relatively slow at an early age and the activation efficiency of solid wastes by reactive MgO is unstable due to the complexity of chemical composition in various solid wastes [8,9]. To synthesize MgO-based cement that is more highly effective in enhancing the early and long-term strength of solidified soils, several blocks of cement with a significantly higher quantity of magnesium have been developed and introduced in soil solidification [4,10-13]. They exhibit many superior characteristics such as fast hardening, high early strength and excellent fire/abrasion resistance and so on. As an air-hardening cement, magnesium oxychloride cement (MOC) is prepared from reactive MgO and chemical reagent $MgCl_2$, and the hydration of MOC occurs in a through-solution reaction, generating the major hydrated products including brucite ($Mg(OH)_2$), phase 5 crystals ($5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$) and phase 3 crystals ($3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$). Besides, magnesium phosphate cement (MPC), prepared by dead burned magnesia (MgO) and potassium dihydrogen phosphate (KH_2PO_4) or ammonium dihydrogen phosphate ($NH_4H_2PO_4$) in the presence of water is one of the most promising alternatives to substitute Ca-based Portland cement, and generated $KMgPO_4 \cdot 6H_2O$ (struvite-k) or $NH_4MgPO_4 \cdot 6H_2O$ (struvite) by an acid-base neutralization reaction. According to the above discussions, it can be concluded that the performance of Mg-based blocks of cement in soil solidification depends greatly on the ratio between components, affecting directly the number of hydrated products and the strength development of solidified soils. The optimal ratio where the strength reaches the peak should be determined before the application of Mg-based blocks of cement in soil solidification.

With the development of Mg-based blocks of cement, an innovative combination of CO_2 carbonation and reactive MgO or MgO-bearing materials was proposed and is attracting more and more attention for the beneficial use in soil solidification [14-17]. In fact, reactive MgO has an excellent capacity to absorb CO_2 emitted from industrial activities such as cement production and mineral calcination, and thus reduce CO_2 emissions by capturing and transforming them into a series of stable hydrated carbonates such as nesquehonite, dypingite and hydromagnesite [16,17]. This can realize us to transform CO_2 gas from industrial emissions to solid Mg-based carbonate minerals that are permanently stable at ambient temperature. For application in soil solidification field, CO_2 carbonation combined with reactive MgO or MgO-bearing materials can not only improve the mechanical performance (strength, bearing capacity etc.) of solidified soils, but also reduce their permeability and porosity owing to the combined physic-chemical impact of pore filling-cementation-skeleton construction. Furthermore, to cut the material cost for CO_2 carbonation and recycle industrial solid wastes that are difficult to be reused on large-scale, various industrial solid wastes with high MgO content such as granulated blast furnace slag, steel slag and fly ash were innovatively introduced in CO_2 carbonation-based solidification approach [17,18]. A portion of MgO originally contained in industrial solid wastes was proved to be efficiently carbonated, but there is still an important fraction of residual MgO in these wastes tested that do not take part in the CO_2 carbonation process. Therefore, how to activate efficiently these MgO residuals in solid wastes and carbonize them to form stable and permanent carbonates is deemed as an intractable problem to address in the future. Some preliminary attempts at the dissolution of magnesium from solid wastes to facilitate its combination with CO_2 have already been made for the moment, but it still requires many more efforts on this topic to develop a cost-effective and efficient approach to carbonize as much as possible these MgO minerals contained in solid wastes. It would become a crucial and innovative research issue in the soil solidification field that deserves to be systematically investigated in the coming future. Especially, the environmental compatibility between Mg-based carbonation and treated soils should be also considered for the potential application in various construction domains including ground improvement and concrete fabrication etc.

The above discussions summarized the research motivation and development process of green, low-carbon and efficient Mg-bearing cementitious binders oriented for soil solidification in the domains of soft ground improvement and waste sludge treatment. Especially, concerning the prospective research, the carbonation of industrial solid wastes and their combination with reactive materials such as MgO would be a promising and high-valued waste recycling technique for soil solidification and the green construction sector.

Conflict of Interest

There is no conflict of interest.

References

[1] Nicholson, P.G., Kashyap, V., Fujii, C.F., 1990. Lime and fly ash admixture improvement of tropical Hawaiian soils. Transportation Research Record. 1440, 71-77.

[2] Tremblay, H., Duchesne, J., Locat, J., et al., 2002. Influence of the nature of organic compounds on fine soil stabilization with cement. Canadian Geotechnical Journal. 39, 535-546.

[3] Zentar, R., Wang, H., Wang, D., 2021. Comparative study of stabilization/solidification of dredged sediments with ordinary Portland cement and calcium sulfoaluminate cement in the framework of valorization in road construction material. Construction and Building Materials. 279, 122447.

[4] Wang, D., Zhu, J., Wang, R., 2021. Assessment of magnesium potassium phosphate cement for waste sludge solidification: Macro and micro-analysis. Journal of Cleaner Production. 294, 126365.

[5] Gartner, E., 2004. Industrially interesting approaches to "low-CO_2" cements. Cement and Concrete Research. 34(9), 1489-1498.

[6] Dung, N.T., Unluer, C., 2017. Carbonated MgO concrete with improved performance: The influence of temperature and hydration agent on hydration, carbonation and strength gain. Cement & Concrete Composites. 82, 152-164.

[7] Yi, Y., Li, C., Liu, S., et al., 2015. Magnesium sulfate attack on clays stabilised by carbide slag and magnesia-ground granulated blast furnace slag. Géotechnique Letters. 5, 306-312.

[8] Wang, D., Wang, R., Benzerzour, M., et al., 2020. Comparison between reactive MgO and Na_2SO_4-activated low-calcium fly ash solidified soils dredged from East Lake, China. Marine Georesources & Geotechnology. 38(9), 1046-1055.

[9] Wang, D., Wang, H., Di, S., 2019. Mechanical

properties and microstructure of magnesia-fly ash pastes. Road Materials and Pavement Design. 20(5), 1243-1254.

[10] Wang, D., Benzerzour, M., Hu, X., et al., 2020. Strength, permeability, and micromechanisms of industrial residue magnesium oxychloride cement solidified slurry. International Journal of Geomechanics. 20(7), 04020088.

[11] Ma, J., Zhao, Y., Wang, J., et al., 2010. Effect of magnesium oxychloride cement on stabilization/solidification of sewage sludge. Construction and Building Materials. 24, 79-83.

[12] Wang, D., Chen, Z., Gao, X., 2022. Sustainable improvement of magnesium oxychloride cement solidified waste sludge with fly ash inclusion. Journal of Materials in Civil Engineering. 34(12), 04022317.

[13] Wang, D., Zhu, J., Zeng, G., 2022. Comprehensive evaluation on magnesium potassium phosphate cement-mineral additive stabilized waste sludge. Marine Georesources & Geotechnology. 40. doi: 10.1080/1064119X.2022.2146553.

[14] Harrison, A.J.W. (inventor), 2008. Reactive Magnesium Oxide Cements. US Patent. 7, 347, 896. 2008 Mar 25.

[15] Harrison, A.J.W. (editor), 2003. New cements based on the addition of reactive magnesia to Portland cement with or without added pozzolan. Proceedings of the CIA Conference: Concrete in the Third Millennium. Brisbane, Australia: CIA. p. 1-11.

[16] Liu, S.Y., Cai, G.H., Cao, J.J., et al., 2020. Influence of soil type on strength and microstructure of carbonated reactive magnesia-treated soil. European Journal of Environmental and Civil Engineering. 24(2), 248-266.

[17] Wang, D., Xiao, J., Gao, X., 2019. Strength gain and microstructure of carbonated reactive MgO-fly ash solidified sludge from East Lake, China. Engineering Geology. 251, 37-47.

[18] Wang, D., 2021. Solidification performance and micro-structure characteristics of dredged sludge. Science Press: Beijing, China.