Silesian University of Technology

PhD Thesis

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The assessment of the applicability of cementitious composites incorporating electrochemically exfoliated graphene in building structures

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ABSTRACT

Nowadays, concrete is the most consumed synthetic material in the world. Nevertheless, despite the fact that concrete is presently the most commonly applied structural material, it still features with some significant drawbacks, such as low tensile strength and high vulnerability to cracking. Moreover, of significant importance is also the negative environmental impact of cement and concrete production. Therefore, scientists all over the world are in a continuous quest for new solutions allowing the improvement of concrete performance, in particular its mechanical properties and durability.

As one of the most exciting approaches in materials science, over the past few years, nanotechnology has attracted considerable attention also in concrete technology. Concrete nanotechnology opens up new avenues for the improvement of the properties of cementitious composites as well as for providing novel multifunctional composites with completely new capabilities. In particular, graphene – a 2D carbon allotrope – has emerged as an outstanding nanomaterial exhibiting numerous unprecedented properties with a high potential for civil engineering applications. However, the studies involving the application of graphene in cementitious composites remain, up to date, limited.

The main aim of the thesis was to investigate the potential applicability of a few-layer graphene obtained *via* electrochemical exfoliation of graphite in cementitious composites for building structures applications.

In the framework of this thesis, first, the technologically simple yet efficient method for the preparation of novel cement composites incorporating graphene was developed. Noteworthy, the devised method involves simply the mechanical stirring of graphene with dry cement, prior to adding water. Then, several cement mortars with the addition of graphene, graphene oxide and graphite flakes were manufactured and the consistency measurements were performed. Electrochemically exfoliated graphene proved not to deteriorate the consistency of processed cement mortars, thus outperforming the commonly used graphene oxide.

Furthermore, the effect of the aforementioned nanomaterials on the mechanical properties, these are uniaxial compressive and tensile strength, the deformability, i.e. Young's modulus, Poisson's ratio and failure strains as well as the microstructure of as produced cement mortars was investigated. The addition of graphene proved to significantly enhance the mechanical properties of cement composites, in particular the tensile strength of cement mortar incorporating 0.05 wt.% of graphene (dosage by weight of cement) was remarkably increased by 79%. The improved mechanical properties of the graphene-cement composites originate from the modified microstructure of these composites. The addition of graphene promotes the cement hydration resulting in more compact and densified microstructure with increased amount of C-S-H phase.

Moreover, the corrosion resistance of the cement mortars incorporating graphene in a chloride environment was investigated. The chloride penetration depth and the exact chloride content were determined for cement mortars stored in NaCl solution. It turned out that the addition of 0.05 wt.% of graphene significantly reduces the chloride penetration depth by 50%.

Considering the potential applications of graphene-cement composites in Structural Health Monitoring, the electrical measurements of cement mortars with graphene were also conducted. The addition of 1.0 wt.% of graphene proved to tremendously decrease the resistivity of Portland cement composites, thus representing the percolation threshold.

Finally, the effect of graphene on the behavior of cementitious composites in the complex stress state was evaluated in order to determine the boundary surface for the new composite. Generally, the effect of graphene addition on the behavior of cement mortar under the multidirectional loading is marginal, however, due to the tremendously increased tensile strength, the parabolic cap of the tensile meridian should be further evaluated.