Nanotechnology to Manipulate the Aggregate-Cement Paste Bond: Impacts on Concrete Performance

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EXTENDED ABSTRACT

It is well recognized that the area of contact between the cement paste and aggregates, known as the interfacial transition zone (ITZ), is one of the most vulnerable areas of concrete. The microstructure of this interface, the nature of its chemistry, and the high porosity coupled with the aggregate’s surface and mineralogy affect the adhesion between the aggregate and cement paste and therefore, dictate the performance of concrete. Problems arise at this adhesion point because there is no current method in place to account for the differing aggregate assortments used in concrete. Currently, aggregate is tested to be sure it behaves as predicted and is useable, leaving out marginal sources. As concrete is the number one building material in the world and we continually consume this material, it is vital that we allow ourselves to use these less desirable sources, which leaves us with the question of how. How can we improve the material at the surface as to not decrease performance or jeopardize the durability? Can we engineer the properties of the ITZ using nanoporous films?

The traditional strategy for improving the nature of the ITZ has been the successive addition of different pozzolanic materials having a high surface area/particle size relation to the cement-paste fraction. However, the beneficial effects of these additions to the ITZ are diluted, since these additives largely end up in the bulk of the cement paste, where they attempt to manifest their improvements. The aim of this research is to show the benefit and practicality of depositing pozzolanic materials as thin films on the surface of aggregates used for concrete production to specifically improve the ITZ. Our preliminary results have shown that a small dose of these additives can significantly modify the adhesion between aggregate and cement paste and porosity in the ITZ.
The consequence of this approach of adding nanoporous thin films to aggregate surfaces is an overall improvement of the principal mechanical properties of concrete. In particular, mortar made with a 0.03 silica-oxide/cement ratio and with the silica oxide deposited as a surface coating of just 1/3 of the total fine aggregates showed a 40% improvement in compression, flexural, and tensile strength at early ages along with significant decrease in the porosity of the ITZ. These results clearly indicate that the addition of silica oxides into concrete as thin films on aggregate surfaces has a high potential for improving overall performance of this highly consumed construction material. The direct application of these additives into the ITZ will increase their efficacy with respect to traditional supplementary cementitious materials. This new technology could be easily implemented to produce a stronger and more durable concrete.

As we look further into the mechanism for this improvement, we remember the question “Can we engineer the ITZ?” Although these mechanical improvements are positive, what is truly the potential of the material? We took a closer look at the ITZ, and through microscopy, we noticed that our materials reduce the porosity in the area of concern. We believe that these materials are undergoing a pozzolanic reaction and not simply increasing the surface area of the aggregate, allowing for adhesion simply due to roughness. As such, this material opens the door to solve further problems.

Currently, some aggregate sources are deemed unusable because deleterious microfines (particles <75 µm) found attached to the aggregate and/or degradation mechanisms, such as alkali-silica or alkali-carbonate reactions (ASR and ACR), threaten the integrity of the concrete. It is well known that clay minerals strongly absorb water and possess pozzolanic characteristics; they have extremely high potential to cause shrinkage and cracking. By placing our pozzolanic, nanoporous films over the clay, we can enable the transformation of the clay minerals into traditional hydration products when in the presence of high pH conditions supplied during concrete hydration.

We believe that ASR and ACR distress can also be ameliorated by using these nanoporous coatings. Depending on the nature of the nanoparticles needed to counteract the aggregate and microfine reactivity, two main mechanisms of amelioration are envisioned:

1. Isolating the source of reactive minerals. Some of our nanoporous films are inert and insoluble in the basic environment created by the cement paste. These films have negatively charged pores and will consequently prevent the diffusion of -OH groups to the surface of the aggregate, in effect, preventing reactions.

2. Creating an inhospitable ITZ for the development of ASR and ACR. Here the presence of highly reactive nanoporous films on aggregates will create an ITZ having little Ca(OH)₂ and thus, be an undesirable zone for the development of ASR.

The use of this new method for applying additives in concrete is expected to be much more efficient than the traditional dispersions of supplementary cementitious materials in cement paste. Furthermore, it will help to create a material with improved characteristics and less energy demand for maintenance. As an example, the higher strength developed at early ages will be not only useful for accelerating construction and rehabilitation operations but also in other areas of construction, such as joining compounds for use in the rapid construction of precast railway and highway bridge structures. Additionally, a concrete with higher values of tensile and flexural strength will likely show a reduced tendency for crack development, while a lower porosity in the ITZ should grant higher resistance to D-cracking. The overall results should be more durable concrete infrastructures by improving the highly vulnerable ITZ.

Key words: aggregate-cement paste bond—concrete durability—nanoporous thin films—porosity—mechanical properties