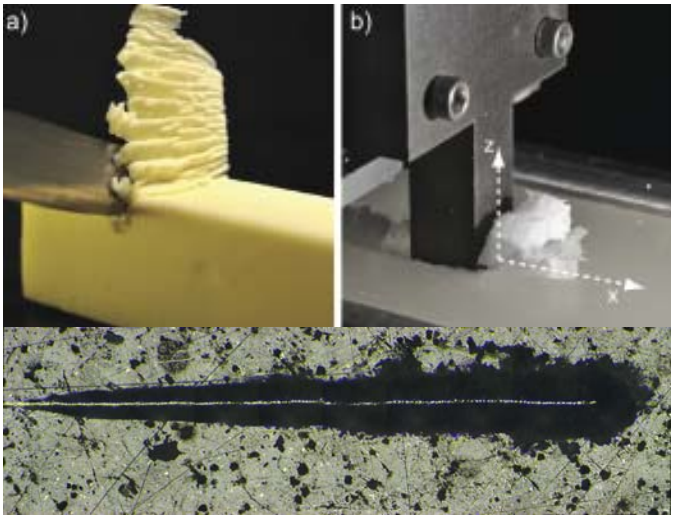
Toughness Simply by Scratching

Problem

Ask any concrete engineer what s/he fears most: It is cracking. But the toolbox of concrete engineers does not typically extend beyond the compressive strength, far removed from fracture properties of concrete that are critical to evaluate, mitigate and reduce the risk of cracking. Classical fracture tests on concrete are too complicated to be transferred from the lab bench to day-to-day engineering practice. Recent research at M.I.T. now shows that the scratch test may well be a solution to this issue. The idea of the scratch test is simple. It suffices to recall the scraping of cold butter with a knife; that is, plowing and cutting with a scratch device (knife) the surface of a weaker material (butter). Provided with an accurate fracture mechanics model, it is possible to employ this technique to determine the fracture toughness of all types of material, from butter to steel, and concrete. Such a highly repeatable technique is invaluable for research on sustainable concrete materials at multiple scales; and it will be critical for the implementation of novel concrete engineering solutions in our infrastructure systems.



The Scratch test on (a) butter, (b) paraffin Wax, and scratch profile after micro-scratching of cement paste (max depth= 0.12 mm, length=3mm).

Approach

Here we focus on scratching as a fracture process, and approach this problem through a combination of well controlled experiments, dimensional analysis and theory. First, we performed precision tests on paraffin wax, which we regard as a model material. Dimensional analysis enabled us to identify the mechanical parameters involved. We then developed a theoretical framework based on energy principles to rationalize the process. Our predictive model is validated for a wide range of materials, cutter-blade geometries and length scales.

Findings

Application of this new technique to cement pastes prepared at different water-to-cement ratios reveals that the macroscopic fracture toughness is enhanced by unhydrated clinker present in the hardened cement paste. Moreover, a comparison of micro- and macro scratch results indicate that the fracture toughness of C-S-H is 4-5 times higher than the one of cement paste.

Impact

Scratching a weaker material with a tougher one is no doubt the most elemental conceptualization of a materials test ever conceived by mankind. This research highlights the relevance of the scratch test for assessing fracture properties of cement-based materials at multiple scales. This research makes it possible to identify reserves in concrete design that could enhance the crack resistance of concrete materials. Moreover, the test can be conducted over a period of time on the same sample that provides a benefit of evaluating the evolution of properties with time. All this makes the scratch test most appealing for innovative concrete applications.

More

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