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Can self-healing mechanism helps concrete structures sustainable?

Senot Sangadji[a,*]

[a]*Civil Engineering Department, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, Indonesia*

Abstract

Concrete is quasi-brittle material susceptible to cracking under tensile or shear stress. In case of continuous network of crack is formed, concrete structure becomes permeable and embedded rebar may be exposed to ambient air, hence escalating the risk of material degradation. On the other side, concrete infrastructures industry is facing pressing sustainability issues. Concrete production consumes high amount of energy and produces large amount of CO2 emission. The scale of the problem is even greater in the event of many concrete structure premature failure which consumes more raw material for rebuilding. Designing new infrastructures for longer service life by improving concrete (materials and structure) durability is one solution to overcome the dilemma. One promising concept is by incorporating self-healing mechanism found in nature into cement-based materials / concrete structural element.

This paper presents inherent autogeneous healing which occur due to its heterogeneous nature of concrete. This contribution also demonstrates some laboratory proven bio-inspired techniques that makes concrete materials and/or structural element self-healing autonomously. It involved diverse methods across several categories. The methods designed have demonstrated to have a good prospect in making concrete structural element self-healing. Finally the paper concludes with the claim that If unavoidable cracks due to inherent brittleness in concrete could be self- sealed/healed/repaired, concrete structure will certainly serve longer service life, making it more durable, therefore sustainable.

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Keywords: Self-healing concrete, bacteria-based healing agent, Porous Network Concrete, Bio-inspired engineering.

* Corresponding author. Tel.: +62-82137659700
E-mail address: s.sangadji@ft.uns.ac.id

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1. Introduction; What are the issues at stake[1]

Throughout history of human civilization, concrete has been gaining a remarkable success. Several layer of calcium carbonate had been utilized as mortar floor as old as nine millennia ago when archaeologist discovered it in Yiftah El in 1985. Concrete had been used as one of primary construction materials in the Roman era when they built Pantheon, unreinforced dome preserved under compression stress, which survives two thousand years up to now. A long history of cementitious material culminates in the modern concrete which demonstrate its noticeable performance in reinforced and prestressed concrete as well as development of ultra-high strength concrete.

Apart from its rich historical narratives, the success of concrete might also be justified by the claim that concrete is currently the most used man-made material. Data support the claim that the amount of concrete used for construction worldwide exceeds 12 billion tons annually, approximately 2 metric tons per person per year. Concrete - the second largest volume material utilized by human after water - is virtually irreplaceable for innumerable large infrastructure developments from the point of view of economy and ecology. It is hard to imagine the progress of modern civilization without concrete serving as major engineering material.

1.1. Pressing sustainability issue

Infrastructures is vital backbone for socio-economic activity and its development encourages productivity and growth. Many countries, primarily developing nations, invest in infrastructure not only to expand their capacity but to influence income distribution. On the other side, the construction, maintenance, refurbishment and demolition of these infrastructure requires huge amount of material cycle and intense energy demand leading into high ecological impact.

Concrete as major infrastructure material embodies energy and carbon emission approximately of about 0.95 MJ/kg and 0.35 kg C/kg, respectively. This value of energy input required from raw material extraction production process, and distribution to its place ready for use, is much lower than many other common construction materials. For instance steel embodied energy and CO_2 is 56.7 MJ/kg and 6.15 kg C/kg, while timber (exclude sequestration) has 8.5 MJ/kg and 0.46 kg C/kg, respectively. However, due to high rate of consumption abovementioned, cement and concrete still demonstrates total high energy demand and carbon emissions. These facts imply that efficient use of cement, concretes, and mortars will certainly save the total energy and reducing environmental impact in the life time of the infrastructure.

1.2. Inevitable cracks in concrete; challenge to durability, functionality, and cost of repair

Concrete encounters another challenge from that concrete is quasi-brittle material with properties weak in tension. This intrinsic brittleness is the reason steel reinforcement bar is installed in the tension cross section to carry tensile stress. Concrete cracks is important in this case since it trigger the activation of the steel bar. Within the prescribed crack limit, the crack opening as such may not fail the structure or hamper the overall safety, although it may expose the reinforcement bar to corrosive action from atmosphere.

Apart from macrocracks, microcracks are practically inevitable to the normal concrete. In the event when microcracks form continuous network, concrete will be permeable and the reinforcement bar may be open to ambient air. In this case continuous crack is used as easy mean for ingress of aggressive substances to enter and damage the concrete and corrode the rebar therefore concrete degrades and becomes more vulnerable.

Technically speaking, concrete can succeed a 50 years – or even longer – of life time even though it encounters several degradation processes, e.g. chemical ingress, freeze-thaw cycle, carbonation, etc. However, the presence of cracks triggers more serious problems and limits the concrete capacity to be durable

In many other cases cracks are not desirable. Cracks may threaten the tightness of the retaining structures, e.g. liquid containing structures tank wall, aqueducts, underground spaces, tunnels, etc., which undergo tensile forces. In these cases cracks may facilitate the flow of fluid – liquid or gas – into and out of the structures which considerably alters its serviceability, leads to unhealthy environments within a structure, and diminishes its functionality. In case of waste, highly toxic materials and radioactive disposal container, leakage through concrete is catastrophic and unacceptable.