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Review

Applications of using nano material in concrete: A review

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HIGHLIGHTS

- An overview from the past and current research highlights regarding nano materials in concrete.
- Provide knowledge on the nano materials and application in enhancing human life.

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ABSTRACT

This review paper discussed on the nano materials in concrete. Nowadays, the application of nano materials has received numerous attentions to enhance the conventional concrete properties. Eventually, the introduction of nano materials in concrete is to increase its strength and durability. Nano material is defined as material that contains particle size which less than 200 nm. For the purpose of concrete study, the application of nano materials must be at least 500 nm in size. The addition of ultrafine nano material will help to reduce the cement content by partially replacing cement on weight basis to improve the binding effect. The ultrafine particles of nano material will also help reduce the formation of micro pores by acting as a filler agent, producing a very dense concrete and automatically reduce the growth of micro pores in the UHPC structures. Moreover, this paper presents on the advantages and benefits to enhance the concrete by utilizing nano materials.

Contents

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1. Background of concrete

Evolution of concrete has started from normal grade concrete from grade 5–45 [1,2]. Those grades were popular in 1900's for construction purposes and provide adequate strength for general application. To achieve the design, the mix proportion of normal grade concrete consists of cement less than 380 kg/m^3, normal type of aggregates which is normally granite, medium water requirement and little dosage of superplasticizers [3]. Eventually, starting from 1960, when unique design of structure was created and most of the structure carries load more than 50 MPa up to 95 MPa [4,5]. Since then, a new technology for concrete was created like High Strength Concrete (HSC). HSC can withstand load capacity from 50 MPa until 90 MPa [6,7]. Prior to that, it can be seen that concrete has been utilised for high rise building, bridges and heavy load structures. In terms of mix proportion, HSC requires more cement, high content of aggregates, less water and adequate superplasticizer. To realise this, additives and supplementary materials such as silica fume, fly ash, metakaolin and other pozzolanic were implemented [8–10]. Silica fume was popular in HSC mix due to its ability to increase strength at adequate percentage of cement replacement [10–14]. In contrary, fly ash (FA) addition in HSC mix increases flow ability and also act as natural admixture. Other advantages of using FA in HSC mix is, FA can be an alternative to superplasticizer because it can be replaced at higher dosage and is cost effective [15–18]. Metakaolin (MK) as cement replacement material has started since early 90's [19–23]. Metakaolin is a secondary product of kaolin after undergone heat treatment. The unique feature of MK is it is clay based and allows low water penetration into concrete. Table 1 tabulated the different mix proportion between normal concrete, high strength concrete with silica fume inclusion and UHPC mix used in other studies. Obviously an increase in cement component is seen from those three different concretes. Furthermore, other properties which include aggregates, admixture, water to cement ration and slump are also different.

2. Development of nano concrete

Nano concrete is a concrete that utilises nano materials or a concrete with nano materials added in which the size of the nano particles is less than 500 nm [6,26–31]. It was believed that the addition of nano particles in concrete improve the strength of conventional concrete. Nano particle works in concrete by improving the bulk properties or also known as packing model structure. Ultra or nano particles can perform a superb filler effect by refining the intersectional zone in cement and producing more density concrete. By acting as good filler, their manipulation or alteration in the cement matrix system occurs to provide a new nanoscale structure. Common discrepancies in concrete microstructure such as micro void, porosity and deterioration due to alkali silica reaction will be eliminated. Next, nano materials start to evolve when they become new binding agent which is smaller than cement particles. This improves the structure of hydration gel providing a neat and solid hydration structure. In addition, through the combination of filler and additional chemical reaction in hydration system, a new concrete called nano concrete with durable and enhanced performance has been developed [5,32,33].

Implementation of nano technology in concrete has started since the early millennium in line with the increasing demand for UHPC. Conventional mix formulations of UHPC with the inclusion of silica fumes provide better durability and strength. However, due to limited availability and also the high cost of silica fume makes UHPC technology declining and less demanding compared to HSC. Since then, emerging technology in nano production has developed an alternative to silica fume. By applying nano production concept, a common nano material which mimics the action of silica fume is designed. Nano silica is one of the newest technologies in nano process which has been used as an alternative to silica fume [34]. Since the breakthrough of nano silica, many nano based particles has been developed to be used in concrete. Nano alumina [35], titanium oxide [36], carbon nano tube [37] and polycarboxylates [38] are examples of nano materials used in nano concrete. The following sub-section explains on the production and application of nano materials.

3. Production of nano materials

Since the emergence of nano technology in the late 60's, the idea and concept of producing nano materials have also been developed. The nano size in nano particles produces a greater effect on filler as compared to micro based materials. Guterrez [39] reported that all materials can be transformed into nano particles. The success of nano particle formation is when it can influence the purity or basic chemical composition of parent materials. From that, two methods were developed. The first is top to down approach [40] and the second is bottom to up approach [41]. Selection of those two methods is based on suitability, cost and expertise of nano behaviour [2,24,25]. One of the technique for top to down approach is using milling. The selection of milling technique is due to the availability of the milling machine and its feasibility as any modification can be applied directly without any chemical or electronic devices needed. The definition of top to down approach is, larger structures are reduced in size to nanoscale while maintaining their original properties or chemical composition without any alteration on atomic level control [1,42]. In other words, bulk materials are broken down into nano particles by mechanical attrition and etching techniques. This method is utilised in massive industries. Nano particles produced are in high volume using milling technique since is cost effective and easy to be maintained as it involves more mechanical instruments and less chemical alteration. Another term used to describe top to down approach is contemporary method in nano fabrication. However, uniformity and quality of the final product are inconsistent in top to down approach. Although there are disadvantages in top to down approach, with modification on milling techniques which includes numbers of ball, types of ball, speed of milling and types of jar used, the quality of nano particles can be improved [40,43,44]. High energy ball millings are widely exploited in synthesising nano particles which involves nanomaterials, nanograins, nanoalloy, nanocomposites and nano quasicrystalline materials. The pioneer of milling technique was John Benjamin in producing

Table 1
A summary of concrete properties for different types of concrete obtained from past researchers.

	Compressive strength (MPa)	Flexural strength (MPa)	Porosity (%)	Water absorption (%)	Remark
Normal concrete	10–40	1–10	<30	<30	Mehta and Monteiro [3]
High performance concrete (HPC)	41–100	11–20	12–25	12–25	Hamid, Yusof [49], [50,51]
Ultra high performance concrete (UHPC)	100	20–30	<10	<12	Hartmann [52], [53,54]
Nano concrete	70	12–20	<10	<12	Aïtcin [26], Chong [28]