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Investigation on the effectiveness of chemically synthesized nano cement in controlling the physical and mechanical performances of concrete

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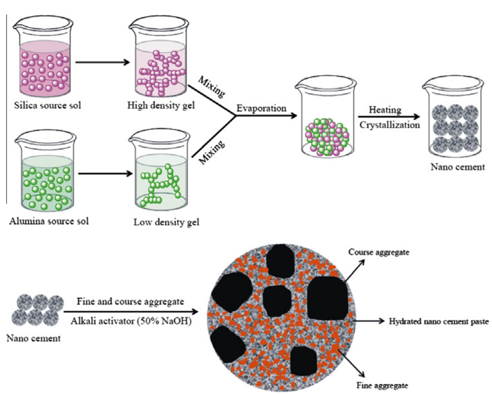
HIGHLIGHTS

- Reduction of CO_2 emission during cement production utilizing alternative way.
- Chemical synthesis of nano cement.
- Effectiveness of synthesized nano cement on mechanical performances of concrete.
- Effective reduction of curing period for building construction.
- Design of a model in controlling the overall performances of nano cement concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

Present investigation deals with the effectiveness of the chemically synthesized nano cement in controlling physical and mechanical performances of concrete. In this investigation, concrete samples were fabricated using variable amounts of aggregates and alkali activator content w.r.t. weight of nano cement. Based on the mechanical properties analyses, it is assessed that chemically synthesized cement is able to produce 43 MPa compressive strength of concrete after 14 days curing instead of 28 days at an optimized amount of aggregates content as well as alkali activator content. Finally, a model has been proposed to explain the overall performances of nano cement based concrete.

1. Introduction

Cement is considered as the primary binding material of the concrete, which is widely being used for the development of modern civil infrastructures. As a principal component of the concrete, the consumption of cement increases tremendously for the construction purpose. Accordingly, the current annual consumption of the cement is estimated to be ~2 billion tons in all over the world. Viewing in light of the literature reports [1], it is assessed that ~700–800 kg of the CO_2 is liberated during the production of 1 ton cement. It is well known that the CO_2 is one of the major constituents of the greenhouse gases causes global warming and environmental pollution. Hence, the massive production of cement emits enormous amounts of CO_2, which in turn directly participates in befalling of the global warming. Therefore, an immediate alterna-

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tive approach is needed to be established for the production of cement, which will reduce or avoid the emission of CO_2. In resent, the attention of the scientist and technologists attracted towards nanotechnology for transporting revolution in the material world, explaining the structures and properties at the nano scale level. Therefore, utilization of the nanotechnology in the production of the cement would have the encouraging impact, which will definitely bring revolution in the cement and concrete research. If the nanotechnology is integrated with the traditional construction and building research, then the new materials will possess high value and smart properties [2–6]. In the existing literature, it is reported that the nano-concrete can be defined as a concrete made with Portland cement particles that are less than 500 nm as the cementing agent [7]. Additionally, the bottom up nano engineering process viz., incorporation of nano SiO_2, TiO_2, Al_2O_3, Fe_2O_3, nano fiber or nanotube and nano clay, etc. into cement system during mixing has established itself as a promising method, which encompasses the structure at the nanometer scale to develop multifunctional cementitious composites with superior mechanical performance and durability [2–4,8]. Accordingly, nano material implanted cement based material possesses a range of novel properties such as: high ductility, self-healing, self-crack controlling ability, low electrical resistivity, and self-sensing capabilities [9]. Moreover, it is also reported elsewhere that the application of the nano porous thin film on the aggregate surfaces before mixing of the concrete not only brings a range of novel properties, but also improves the interfacial transition zone (ITZ) in concrete system [10–12]. Table 1 represents comparative effects of the different nano material on the performances of the concrete.

Reviewing the literature, it is apparent that the nanotechnology is efficient to bring several encouraging impact towards the development of high performance and sustainable construction materials, however process is unable to reduce CO_2 emission. In this context, an alternative technique has tried to be established to produce cement without emitting the CO_2. In a recent study, we have discussed the hydrothermal synthesis of nano cement using nano silica, sodium aluminate and calcium nitrate, and the performance of the synthesized material as well. In the present investigation, we have studied the impact of chemically synthesized nano cement on physical and mechanical performances of concrete. Chemically synthesized nano cement is demonstrated to be very effective not only to control the physical properties viz., slump value, air content % and bleeding capacity of concrete, but also to produce ~43 MPa compressive strength of the concrete after 28 days curing at an optimum amount of aggregate content and alkali activator content.

2. Experimental procedure

To evaluate the effectiveness of the chemically synthesized nano cement on the physical and mechanical performances of the nano cement based concrete, we have described the procedure for the synthesis of the nano cement using the hydrothermal method, prior to the fabrication and characterization of the nano cement based concrete. The chemical synthesis of the nano cement as well as fabrication of the nano cement based concrete are systematically described below.

2.1. Chemical synthesis of the nano cement

Nano cement was synthesized using silica source and alumina source. The silica source was prepared using nano silica purchased from Dae-gu Company Ltd. Korea, with the deionized water in a Pyrex flux. Similarly, at the same time, in an another Pyrex flux, alumina source was prepared using sodium aluminate purchased from Sigma Aldrich, USA, with the deionized water. For the preparation of the alumina source, initially, a sodium hydroxide solution (7%) was prepared followed by the addition of the sodium aluminate. The alkaline sodium aluminate solution was then heated at 90 °C with constant stirring until the complete melting of the sodium aluminate in the solution. The sodium aluminate solution was then allowed to cool followed by the addition of the Triethanolamine (TEA) to prevent the precipitation of the alumina source. Hence, the TEA is used as an emulsifier to emulsify the product (aluminum hydroxide) obtained by the hydrolysis of the sodium aluminate. Furthermore, the silica source as well as alumina source was allowed to ripen for 24 h. After 24 h, it was observed that a thick gel as well as a soft gel was obtained from the silica source and alumina source respectively. Thereafter, the soft alumina source gel was mixed thoroughly in the thick silica source gel using a turbine mixture and agitate for 24 h. The product thus obtained by this process was then allowed to dry and crystallize in oven at 105 °C for 15 days. The product thus obtained after crystallization was then washed and membrane filtered to get nano cement. The cement synthesized from the silica source and alumina source contains SiO_2 and Al_2O_3, but, it does not contain CaO. Although, the CaO is the most essential component of the cement. Therefore, to increase the content of CaO, the obtained product was then treated with calcium nitrate with constant stirring for 8 h followed by centrifuge and filtered off. Finally, the obtained product was dried in oven and allowed to fabricate the nano cement based concrete samples.

2.2. Fabrication of chemically synthesized nano cement based concrete

The concrete samples were prepared using chemically synthesized nano cement, fine aggregate, coarse aggregate and alkali activator (50% sodium hydroxide solution). The physical properties of the fine aggregate, coarse aggregate and alkali activator are represented in Tables 2 and 3 respectively. Different batches of concrete were fabricated varying the fine aggregate content, coarse aggregate

Table 1
Effect of different nano materials on the performances of the concrete.

Primary material	Additives/procedure	Particle size	Effect/Performance	Ref.
Portland cement	Nano SiO_2, TiO_2, Al_2O_3, Fe_2O_3, and nanotube/nanofibres were added	~20 nm and 100 nm	Can produce concrete with superior mechanical properties as well as improved durability	[2]
Ordinary Portland cement	Spherical nano particle nano SiO_2, Fe_2O_3 and Multi wall carbon nanotube were added	1–100 nm	Significant improvement in compressive strength as well as Young's modulus and hardness of the concrete	[3]
Portland cement	Spherical nano-Fe_2O_3 and nano-SiO_2 were added	15 nm	Mortar showed higher compressive strength as well as flexural strength	[4]
Portland cement	Nano-size ingredients such as alumina, silica particles and carbon nanotubes were added	<500 nm	Nano cement can create new materials, devices and systems at the molecular, nano and micro-level	[7]
Portland cement	Single wall and multi wall carbon nanotube were added	–	Cement materials showed superior mechanical, electrical and thermal properties	[8]
Nano SiO_2, $NaAlO_2$ and $Ca(NO_3)_2$	Using the hydrothermal method, a new type of cement material produced	167 nm	Can able to control physical and mechanical performances of the concrete, produce ~43 MPa compressive strength, Avoid CO_2 emission during production	Present work

Table 2
Physical properties of the fine and coarse aggregates.

Type of aggregate	Size (mm)	Specific gravity	Fineness modulus	Absorption (%)
Fine aggregate	⩽0.6	2.63	2.48	0.1
Course aggregate	⩽4.0	2.63	6.42	0.7