AN OVERVIEW OF EFFECT OF NANO-MATERIAL MODIFICATIONS IN NON-CONVENTIONAL CONCRETES AND MORTARS

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ABSTRACT. Increasing usage of cement in the construction activities and its direct contribution in carbon dioxide emissions has been a growing concern over the globe. The ecological imbalance created by extraction and uncontrolled usage of natural deposits for meeting aggregate demand in concrete has given an alarming signal to environmental sustainability. This bilateral damage to the environment has forced the construction sector to explore new materials and new techniques to reduce carbon footprint and prevent depletion of natural resources. The use of alternative supplementary cementitious materials like slag, fly ash, metakaoline or any other natural pozzolanic material has proved to be a good alternative for partial replacement of cement. In search of alternative for natural filler material in concrete, researchers have tried industrial wastes, construction and demolition wastes, plastic waste, agro wastes, etc. as aggregate inside concrete. It was observed that the concrete modified with aforesaid two fold agenda was comparatively inferior in selective properties compared to conventional concrete with cement and natural aggregates. In recent years, Nano- particles have caught attention of researchers in concrete sector. The use of these Nano-materials in conventional and non-conventional concrete has delivered outstanding results. This paper presents an overview of effect of these Nano-material modifications in non-conventional concretes and mortars. Use of these Nano- materials in combination with alternative cementitious materials and alternative aggregate materials has given rise to new generation concrete aiming at environmental sustainability.

Keywords: Nano-technology, Sustainability, Nano silica, concrete, mortar

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INTRODUCTION

Worldwide statistics have been focussing on the impact of concrete on the environment globally. The environmental credentials are coming under scrutiny from the viewpoint of carbon footprint resulting from global cement production and ecological imbalance created by aggregate mining for usage inside concrete. As per International Energy Agency Report, April 2018 “The cement sector is the third-largest industrial energy consumer in the world, responsible for 7% of industrial energy use, and the second industrial emitter of carbon dioxide, with about 7% of global emissions” [1]. Approximately 40% of cement plant CO_2 emissions are from the burning of fossil fuel to operate the kiln, 50% due to the manufacturing process and the remaining 10% are accounted for by indirect CO_2 emissions relating to transportation of the finished product [2].

On the other hand, sand and gravel which accounts for major volume inside the concrete are being extracted at a rate greater than their renewal. Globally, about 53 billion tons of material is mined every year. Mining of sand and gravel account for the largest volume of solid material extracted globally [3]. This extraction is having a major impact on ecosystem and environmental sustainability. Use of conventional concrete has emerged as a bilateral worry in construction industry. There is carbon dioxide emission at objectionable levels as a by-product of cement manufacture and also depletion of natural resources in the form of aggregates to meet growing demands in concrete manufacture. Extensive research on use of supplementary cementitious materials as a substitute to cement has been carried out to lower the carbon footprint. Alternatives for natural aggregates are also being investigated to obtain concrete with desired quality. The construction industry is inclined towards using such non-conventional concretes and mortars.

Every attempt is being made to make the non-conventional concrete satisfying acceptability criteria. Recent advancements in field of Nano technology and its applications in field of concrete technology have influenced idea of improving quality of non- conventional concretes and mortars.

NON-CONVENTIONAL CONCRETE AND MORTAR

The present paper aims at review of research findings on Nano-material modifications in non-conventional concretes and mortars obtained by substitution of cement component and/or aggregate component from conventional concrete with supplementary cementitious materials and alternative aggregate materials respectively.

Concrete with Supplementary Cementitious Materials

Portland cement used in concrete and mortars has been direct contributor to carbon dioxide emission over decades. This significant increase in CO_2 emission is presented by Muga et. Al.[4] and as shown in Fig. 1.

To tackle this problem Portland cement has been replaced by supplementary cementitious materials (SCM). Fly ash, blast furnace slag, rice husk ash, silica fume, MSW ash, bagasse ash [5][6] and also natural pozzolanas like calcined clay, calcined shale and metakaoline has been used as SCM successfully [7]. Their filler effect and pozzolanic reaction has shown significant improvement in concrete performance so, these materials are extensively used in normal concrete works as well special concreting operations like high performance and High strength concrete [5].

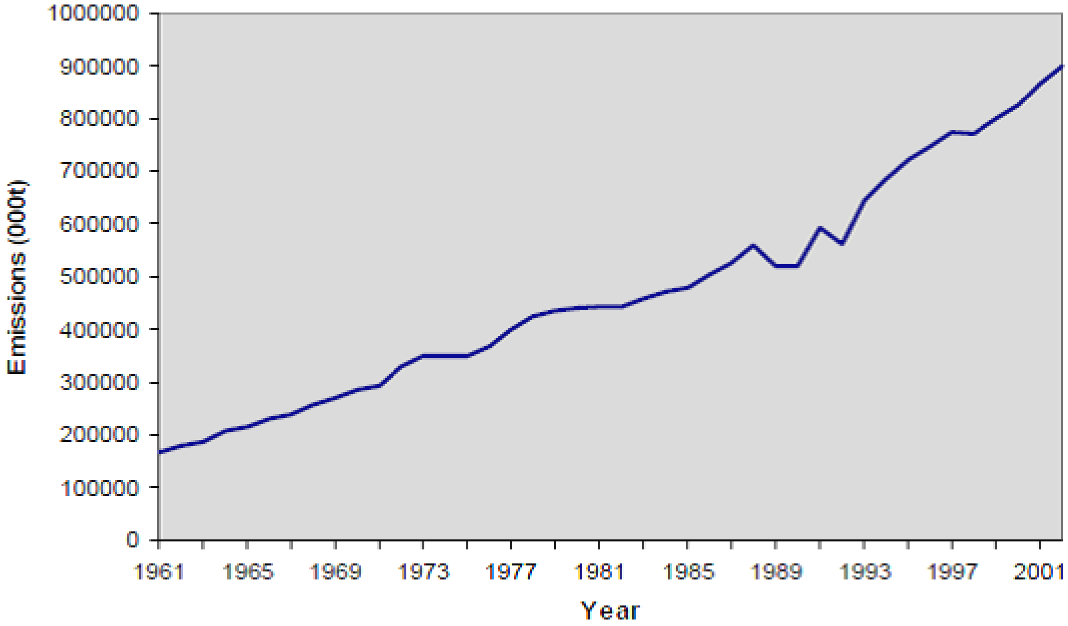

Figure 1 Carbon dioxide emissions due to the world production of cement [4].

Concrete with Alternative Aggregate Materials

Up to 50 billion tonnes of sand and gravel are mined each year to meet soaring demand from construction and land reclamation – making it the largest extractive industry on the planet. United Nations Environment Programme (UNEP) mentions that “Sand and gravel represent the highest volume of raw material used on earth after water”. The caution also follows with the fact that “their use greatly exceeds their natural renewal rates”[8]. Fully or partial replacement of sand and gravel component inside concrete with compatible filler material from industrial waste [9][10], agricultural waste [11], recycled aggregate [12][13][14], construction and demolition waste [15][16][17], plastic waste [18][19], waste glass [20], ceramic waste [21][22] etc. have provided excellent alternative to use of natural aggregates for both coarse and fine fractions.

Extensive and elaborative research to assess the suitability of these alternative materials has been carried out. These research programs to obtain the concrete with quality standards at par with conventional concrete from strength and durability point of view has not found its destination in totality. The material replacement proportions in view of optimum result also demands a positive shift to tackle the issue of rapid depletion of natural resources. The emerging field of Nano-technology has provided a new dimension to research in this sector to meet this qualitative and quantitative demand.

Nanotechnology in Concrete

Extensive research in the field of concrete nanotechnology have confirmed the enhancement of rheological, mechanical and durability characteristics of conventional concrete by various nano materials. Addition of Nano-silica in cement mortar and concrete can result in different effects. These effects are presented by [23].

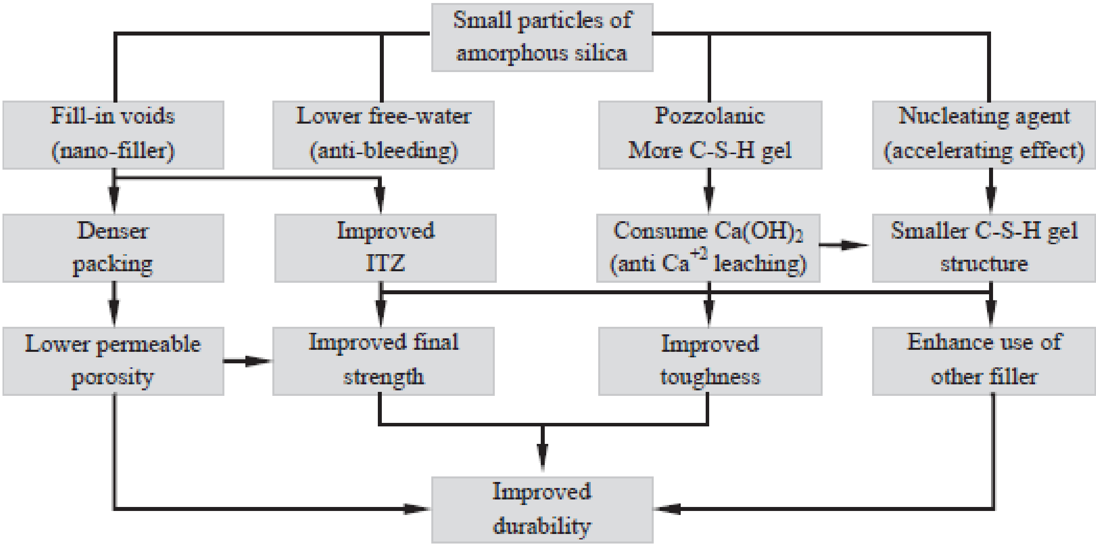

Figure 2 Schematic representation of the effects of adding nano-silica on cement mortar and concrete [23].

The other advantages are formation of small sized $Ca(OH)_2$ crystals and small size clusters of C-S-H. This leads to improvement of the structure of the aggregate contact zone enhancing bond characteristics between aggregates and cement paste. The crack arrest and interlocking between slip planes is another advantage of nano-particles which is responsible for their popularity of usage in conventional and non-conventional concretes [24].

These phenomenal effects on rheological structure of concrete are noteworthy and have been appreciated through researches on normal as well as blended mortars and concretes. Studies have revealed that incorporation of nano silica (NS) in normal concretes leads to enhancement of compressive strength, tensile strength, bending strength, abrasive resistance. Also improved durability properties and reduced permeability characteristics have been reported for normal concretes [25][26][27][28][29].

The well-known attempts to modify the conventional concrete by using supplementary cementitious materials and alternate filler materials for sustainability requirements could not produce concretes satisfying engineering requirements in totality. Recent studies of use of nano technology with specific material and specific property approach is an inventory to achieve the target of aimed sustainable concrete. Replenishment of reduced compressive strength, tensile strength and mitigation of other adverse effects such as lengthened setting times, reduced rate of hydration, increased chloride penetration were outcomes of nano modifications in binary blended concretes. The present literature review aims at effect of nano-modifications on the binary blended non-conventional concretes and mortars.

NANO-MODIFICATIONS IN NON-CONVENTIONAL CONCRETES/MORTARS

Binary blended cement mortars and concretes have been the trend of the industry over recent decades to derive the benefits of environmental sustainability. The Supplementary Cementitious Materials (SCMs) such as Fly Ash (FA) , Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA) , Silica Fumes (SF) and Incinerated sewage sludge ash

(ISSA) have been used for reducing the weight of cement in the concrete mixes to achieve, the desired compressive strength of concrete for use in construction projects [30][31]. The effect of nano-materials especially nano-silica has been investigated on the concretes in which SCMs are used. These research findings are presented in this literature review in Table 1 to Table 3.

Various wastes from industry like iron slag, foundry sand, bottom ash, sewage sludge ash, copper slag, palm oil clinker, glass powder, ceramic waste, plastic waste, M-sand, agro wastes and recycled aggregates from construction and demolition waste have been used as replacement of fine and coarse aggregate in the concrete. Such aggregate blended concretes are found to be deficient in certain qualities which need improvement. Use of nano-materials in such concretes has shown multiple characteristics improvement with respect to strength and durability. The nano-material inclusion effects have been studied for few types of concretes majorly Slag incorporated and recycled aggregate concretes. These studies are focussed in the review at Table 4 to Table 7.

Table 1 Study of nano-material effect on FA incorporated concrete/mortar

AUTHOR	BLENDING COMPONENT	NANO MATERIAL	PROPERTIES
[32][33]	(mortar) FA 40%	Nano clay 0.5-3%	Comp. strength, setting time, heat of hydration, air content, flowability, rate of thixotropy
	FA 30-60%	Nano limestone 5%	Flow & setting, comp. strength, rate of hydration, chemical shrinkage
	FA 20-40-60%	Colloidal Nano silica 2.25-5%	Setting time, viscosity, hydration heat, comp. strength, CH content & morphology
[34]	(Concrete and mortar) FA/slag 50%	Nano silica/silica fume 2%-4%	Rate of heat generation, comp. strength, effect of mixing methods on strength development, chloride ion penetration resistance, microstructure modification
[35]	FA based Geopolymer concrete	Nano silica 3%	Weight change, compressive, split tensile, flexural strength, fracture performance
[36][37]	(Concrete and mortar) HVFA 40-70%	Nano silica 1-6% Nano $Caco_3$ 1-4%	Workability, comp.strength, water sorptivity, permeability, porosity, RCPT, chloride diffusion, accelerated corrosion, microstructure
[38]	(Mortar) FA 25%	Nano alumina 1, 3, 5%	Workability, comp. strength, water absorption, elect. resistivity, porosity, RCPT

[39]	(Mortar) FA 20,25,30%	Nano-Cuo 1-4%	Workability, comp. strength, water absorption, Electrical resistivity, RCPT
[40]	(Mortar) FA 20%	Nano Metakaoline 2.5-10%	Compressive, Flexural strength, porosity, residual CH, Morphology
[41]	(Mortar) FA 5,10% SF 5,10%	Nano Metakaoline 5,10%	Effect of elevated temperatures on mass loss and compressive strength
[42]	(Concrete) FA + PVA 0.5-2%	Nano Silica 1-4%	Rebound number and UPV, Evaluation of comp. strength using prediction model
[43]	(Mortar) FA 25%	Nano silica Nano Al_2O_3 Nano TiO_2 1, 3 , 5%	compressive strength, water absorption, Electrical resistivity, RCPT
[44]	(Mortar) FA /Slag 20-50%	Nano Silica 3nm to 47nm 0.0087-10.9%	Effect on chemical shrinkage
[45]	(Mortar) FA/SF 5,10%	Nano Silica 5,10%	Compressive, flexural strength, FTIR transmission spectra, SEM analysis
[46]	(Mortar, concrete) HVFA/ GGBFS 50%	Nano Silica 05, 1.0, 2.0%	Comp. strength, setting time , heat development, porosity, pore size distribution, chloride penetration
[47]	(Mortar) FA 10-50%	Nano silica Nano Al_2O_3 Nano TiO_2 0.5, 1.25,2.5%	Comp. strength and capillary absorption for binary and ternary nano-incorporation
[48]	(Concrete) FA 5-15%	Nano TiO_2 1-5%	Compressive, flexural, split tensile strength, conduction SEM and XRD, calorimetry, thermo-gravimetric analysis ,

Table 2 Study of nano-material effect on GGBFS incorporated concrete/mortar

AUTHOR	BLENDING COMPONENT	NANO MATERIAL	PROPERTIES
[49]	(Paste and mortar) GGBFS 45%	Nano silica 1-6%	Water consistency, setting times, chemically combined water contents, pH value, bulk density, compressive, flexural strength, XRD analysis, FTIR spectra

[50][51][52] [53][54]	(Concrete) GGBFS 15-60%	Nano silica Nano-TiO_2 Nano-ZnO_2 Nano-Al_2O_3 1-4%	Split tensile strength, CH content, pore structure and pore size distribution, conduction calorimetry, thermo-gravimetric analysis, SEM and XRD analysis

Table 3 Study of nano-material effect on RHA/SF/ISSA incorporated concrete/mortar

AUTHOR	BLENDING COMPONENT	NANO MATERIAL	PROPERTIES
[55]	(Concrete) RHA 0-20%	Nano silica 15nm ,80nm 0.5-2%	Comp. strength, MIP test, thermogravimetric analysis, SEM analysis
[56]	(mortar) RHA 20%	Nano silica 0-5%	Compressive, flexural strength, water absorption, shrinkage and microstructure analysis
[57]	(Mortar) SF	Nano silica Nano-Al_2 O_3 Nano- Fe_2 O_3 0.5- 2.5%	Comp. strength and capillary permeability for binary and ternary nano-incorporation
[58]	(Mortar) ISSA/FA (1:1ratio) 10-30%	Nano Silica (1%-3%)	Consistency, compressive strength, MIP & TEM analysis
[59]	(Mortar) ISSA 1,10,75µm 20%	Nano Silica 0,1,2%	Setting time, compressive strength, SEM analysis, XRD analysis, MIP analysis

Table 4 Study of nano-material effect on concrete/mortar incorporating waste slag as aggregates

AUTHOR	MATERIAL SUBSTITUTE	NANO MATERIAL	PROPERTIES
[60]	Mortar/Concrete Copper slag (40%)	Colloidal nano-silica (0.5-3%)	workability and strength, chloride ion penetration, water absorption, sorptivity and abrasion resistance
[61]	(Concrete) Electric arc furnace slag 20-80%	Nano silica 1%,2%,3%	Compressive strength, Split tensile strength, Flexural strength

Table 5 Study of effect of nano-material on concrete incorporating recycled aggregate (RA) and construction and demolition waste

AUTHOR	MATERIAL SUBSTITUTE	NANO MATERIAL	PROPERTIES
[62]	RA 25, 50%	Nano silica 1,2%	Compressive, tensile strength, volume of permeable voids, sorptivity, chloride penetration
[63]	RA 0%,100%	Nano Silica 2% direct mixing 2% presoaked	Comp. strength, volume of permeable voids, chloride ion penetration, sorptivity, MIP, microstructure analysis
[64]	RA 30%	Nano silica Nano limestone 1, 2%	Crack propagation using digital image correlation technique, comp. strength, microstructure properties, water absorption, porosity
[65] [66]	RA 0,100%	Nano silica 0.75, 1.5, 3%	Comp. strength, modulus of elasticity, water absorption, BSEM image analysis, micro hardness, porosity of ITZ, unhydrated cement content
[67]	RA 0,50,100%	Nano silica 0.4- 1.2%	Comp. strength, Microscopic and SEM analysis
[68]	RA 0,100%	Nano silica 1.5,3%	Workability, strength, water absorption, durability characteristics
[69]	(mortar) RA(fine) 100%	Graphene oxide 0.05-0.2%	Static and dynamic properties, storage modulus, pore structure, microstructure
[70]	Waste clay bricks 10-25%	Nano silica 0.5,1%	Compressive strength Water absorption

Table 6 Study of effect of nano-material on concrete/mortar incorporating Glass waste/crumb rubber as aggregates

AUTHOR	MATERIAL SUBSTITUTE	NANO MATERIAL	PROPERTIES
[71]	(Mortar) Glass waste 25-100%	Nano silica 0, 3%	Consistency, compressive, flexural strength, water absorption, porosity, bacterial properties
[72]	Crumb rubber (10,20%) Fly ash (0,50%)	Nano silica 0,1%	Flexural strength Fatigue strength

Table 7 Study of effect of nano-material on concrete/mortar incorporating other filler materials as aggregates

AUTHOR	MATERIAL SUBSTITUTE	NANO MATERIAL	PROPERTIES
[73]	Expanded shale ceramsite 25-100%	Nano silica 0.2, 0.5, 1%	Compressive, flexural strength, SEM morphology, Energy dispersive X-ray spectroscopy
[74]	(Mortar) M-sand Marble powder, RHA	Nano-Al_2O_3 Nano- Fe_2O_3 0.5-2%	Split tensile strength, comp.strength
[75]	Granite waste	Nano granite waste 5,10%	Comp. strength, SEM analysis

CONCLUSIONS

In the field of sustainable construction development, the construction industry stressed use of supplementary cementitious materials and waste filler materials in concrete to reduce resource consumption, waste as well as carbon emissions. The depletion in quality of concrete in the process was mitigated by application of Nanotechnology to the modified concrete. Extensive research with specific material and specific property approach has been presented in this paper. The research findings confirmed positive impact of nano-materials in enhancing rheological behaviour, cementitious material hydration, early age strength gain, long term strength and durability of binary modified concretes. However Marginal differences were observed in optimum content of usage of nano-materials. The fact that improvement in mechanical behaviour and durability characteristics being the common minimum outcome of the nano-modifications, following findings worth mentioning

1. Nano material inclusion in fly ash based mortars can lower strength loss at elevated temperatures.
2. For fly ash bended mortars, use of higher nano-material content hampers enhancement of properties like electrical resistivity, chloride penetration and porosity.
3. Single use, binary use and ternary use of different nano-materials in combination has been investigated. With favourable outcomes in majority of findings, even negative effects were reported on physical and mechanical properties in RHA blended mortars.
4. In aggregate replaced concretes/ mortars, pozzolanic action and pore filler of nano-materials was responsible for enhancement of properties of modified concretes.
5. The concrete with recycled aggregates showed better results when aggregates were soaked with nano-solutions rather than direct mixing. Nano materials failed to improve elastic modulus of recycled aggregate concrete.
6. Binary concrete with nano-material modification showed improvement in dynamic strength along with static strength.
7. Fatigue and flexural strength of RCC pavement made with crumb rubber as fine aggregate was enhanced with nano-material addition.

8. The quality depletion due to lack of cohesion of alternative materials like waste glass/rubber with cement paste is overcome by addition of nano-materials. It also improved bactericidal properties.

FUTURE SCOPE FOR RESEARCH

Concretes and mortars are being modified with different alternative materials nowadays for want of carbon credit and natural resource saving. Only selected materials like flyash, GGBFS, RHA, recycled aggregates, some industrial slags have been investigated after nano-material modifications. However some characteristics like sulphate resistance, alkali silica reaction, carbonation characteristics have not been noticed during the review. Investigation of such characteristics and study of nano-material modifications of other binary blended concretes/ mortars has vast scope in research field.

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