ENGINEERING JOURNAL

Article

The Role of Nano-Technology in Sustainable Construction: A Case Study of Using Nano Granite Waste Particles in Cement Mortar

E. S. Bakhoum[a], G. L. Garas[b,*], M. E. Allam, and H. Ezz

National Research Centre, Egypt, Elbohouth St., Dokki, Giza, Egypt
E-mail: [a]emaduk@gmail.com, [b]gihangaras@yahoo.com (Corresponding author)

Abstract. Better understanding of the properties of cement-based materials, one of the most widely used building materials, at the nano-scale is crucial to improve its functionality in the built environment. This paper presents areas of using nano-materials in improving the characteristics of cement-based materials as well as introducing a new role of nano-technology together with waste management in enhancing the concept of sustainable construction.

A case study on the use of nano-granite waste particles as a replacement of cement and fine aggregate in mortar production is presented.

The research concluded that replacing 5% cement and 10% sand with nano-granite waste in the mortar mix increased the compressive strength of the green mortar by 41% compared to that of the control mix (CM). SEM images reinforced this result as the green mortar mix showed maximum density and minimum micro cracks and number of pores.

A comparative study between the green mortar and traditional mortar was carried out using sustainability indicators to examine the environmental, social and economic implications. The environmental and social attributes showed a saving of 10% in the field of resource consumption, whereas savings in energy consumption and CO_2 emissions reached 5%. The economic field showed saving of 6.5% indicating promising results in enhancing the sustainable construction industry.

Keywords: Sustainable construction, nano-technology, nano-granite waste, green buildings.

ENGINEERING JOURNAL Volume 21 Issue 4
Received 11 October 2016
Accepted 17 January 2017
Published 31 July 2017
Online at http://www.engj.org/
DOI:10.4186/ej.2017.21.4.217

DOI:10.4186/ej.2017.21.4.217

1. Introduction

Nanotechnology is the re-engineering of materials through controlling the matter at the atomic level. In general, nanotechnology can be referred to understanding of matter on the Nano scale (from 0.1 nm to 100 nm), where, one nanometer is a billionth of a meter [1]. The key in nanotechnology is the size of particles because the properties of materials are dramatically affected under a scale of nanometer [10-9 meter] [2].

Nanotechnology is a recent promising field in terms of improving environmental aspects including but not limited to energy savings, minimized reliance on non-renewable resources, as well as reducing waste, toxicity and carbon emissions. According to Ganesh (2012) [3], nano-technology can contribute to produce products with unique characteristics which could significantly provide solutions to achieve sustainable construction development as well as opening up new possibilities for ecologically oriented facilities.

When considering the built environment, cement-based materials such as concrete, mortar and cement bricks are considered widely used construction materials. Better understanding of the properties of those building materials at the nano-scale can lead to improve their functionality. Moreover energy conservation and reducing greenhouse emissions in the building environment can be a reality due to nano-materials emerging as insulations and energy storage materials. These materials are coupled with thermal energy storage properties that can reduce the operational energy consumption in a built environment to a great deal. Other applications such as antimicrobial surfaces would reduce the resource consumption and lengthen the life cycle of material usage in the industry, thus would drive towards sustainable practices [1, 2].

Moreover, land filling as well as recycling cost of waste materials generated from most industries such as marble, granite, rubber, plastic, ceramic, textile etc; is leading to waste disposal crisis. Such types of wastes that have pozzolanic activities are increasingly used in the construction industry as a partial replacement with cement in order to reduce the carbon dioxide emission from the cement industry and environmental pollution [4]. During the renovation or demolition of buildings, engineered nano-materials (ENMs) contained in former construction materials are recycled or become construction waste. Currently, information about disposal of ENM waste into the environment and its negative impact is unknown [5].

Several attempts had been made recently to benefit from the use of nanotechnology science and applications in the field of cement based materials production as a substitute for cement or sand with various proportions. Most of this research depended on using high cost raw materials (e.g. Silica particles) in a nano-scale to enhance the properties of cement based materials specifically concrete and mortar.

This paper will introduce the successful areas of using nano-materials in improving the characteristics of cement-based materials as well as introducing a new role of nano-technology together with waste management in enhancing the concept of sustainable construction.

A case study on the use of nano-granite waste particles as a replacement of cement and fine aggregate in mortar production will be presented aiming to move towards more green buildings.

2. Applications of Nanotechnology in the Construction Industry

There is a large scope of nanotechnology applications in construction materials that can result in remarkable benefits for civil engineering.

2.1. Nano-Materials in Building Products

Recent research efforts aimed to study the role of nanotechnology for the construction applications in the area of building materials. Incorporating nano-particles in the production of these materials enhanced its properties, strength and durability. Moreover, the toughness, shear, tensile and flexural strength of cement based materials were enhanced.

Bhuvaneshwari et al. (2011) [2] presented the application of nano-technology on several building materials among which:

Nano cement: Cement particle size can be reduced or modified to be in nano-size. For example, nano-tubes and reactive nano-size silica particles can be added to cement for this reason. It was found that using nano-cement in concrete mix will be more effective than using carbon fibers or nano-carbon tubes in concrete.

Nano steel: Addition of copper nano-particles reduced the surface unevenness of steel which accordingly limited the increase in steel stress and hence fatigue cracking. Besides, vanadium and molybdenum nano-particles improved the fracture problems resulting from high strength bolts. Researchers reported that stronger steel cables can be produced by refining the cementite phase of steel to a nano-size.

Nano glass: Glass can be developed to have self-cleaning, sterilizing and anti-fouling properties by using TiO2 in nano form as a glass coat.

Nano-coat for concrete: Nanometer thick coatings which are durable and could have self-cleaning and self-healing properties can be used to protect the concrete structures from abrasion and chemical attack. The nano-sized materials, for example nitrides, phosphors, nano Al_2O_3 can reveal unique surface properties that have the ability of adsorption charged species on it.

Nano Particles for fire protection: Nano-cement mixing with carbon nano-tubes (CNT) with the cementious material can produce fiber composites of high strength and fire resistance.

Nano Sensors for Concrete Structures: Smart nano-dust (aggregate) sensors can be used as wireless sensors that embedded in concrete, sprinkled on the surface of the structure or incorporated into the mix. Nanotechnology-based sensors can be used in concrete structures for quality control and health monitoring by using the information on changes in density and viscosity, shrinkage, moisture, chlorine concentration of concrete.

Nano-materials in concrete: Nano SiO_2, Al_2O_3, TiO_2, quartz can be used to enhance the concrete properties and produce high strength, high performance and self-compacting concrete.

2.2. Nano-Materials in Concrete Mixtures

Although nano modifications to concrete is an active research area, but still the enhancements are slow compared with the other fields [1, 6]. This is due to the lack of understanding of two things: the concrete at nano level, and the modifications that can be done by nano materials to concrete [7]. The experimental techniques nowadays facilitated the study of concrete at the micro and nano level. Therefore, many researchers studied the effect of adding different nano particles to concrete to enhance its properties.

Adding nano-silica to concrete increased its strength, flexibility, workability, and durability [6, 8–10]. It was found that the nano-silica particles increased the viscosity of the concrete fluid phase and have the ability to fill the voids between the cement particles. The nano silica also reacts with Calcium Hydroxide and produce more Calcium Silicate Hydrate (C-S-H), which controls almost all concrete mechanical and transport properties [7] resulting in high strength than traditional concrete. In addition, it was found that adding nano silica to concrete enhance the hydration process of cement due to the large reactive surface area of nano particles [6, 11].

Li et al. (2005) [12] studied the effect of adding Carbon Nano Tubes (CNTs) both Single Walled (SWCNTs), and Multi Walled (MWCNTs) on the concrete properties. They found that CNTs displayed 100 times more theoretical strength than that of steel while just having one sixth of steel specific weight. Adding CNTs also increases the C-S-H amount in concrete. Moreover, CNTs reduces the C-S-H phase porosity, which results an increment in Young's Modules, flexural strength, compressive strength, durability, and a decrement in autogenous shrinkage [12, 13]. Furthermore, Bhuvaneshwari et al. (2011) [2] found that adding small amount of CNT (1% wt) improves the mechanical properties of concrete. MWCNT shows the best improvements in concrete strength including compressive and flexural strengths when compared to traditional concrete.

Although nano TiO2 is not participating in the concrete reaction, Jayapalan et al. (2009) [14] found that it improves the compressive strength, flexural strength, and abrasion resistance of the concrete. They also found that the rate and the peak of hydration of concrete were increased.

Nazari et al. [15] found that by partial replacement of cement with nano Fe_2O_3 particles, the flexural and compressive strengths of concrete are improved. In addition, it was found that partial replacing of cement by nano Al_2O_3 particles enhanced the mortar properties including compressive, flexural, and split tensile strengths while decreases its workability [16, 17].

Figure 1 illustrates the incremental increase in flexural and compressive strengths of concrete by adding various nano-materials to the mix [1].

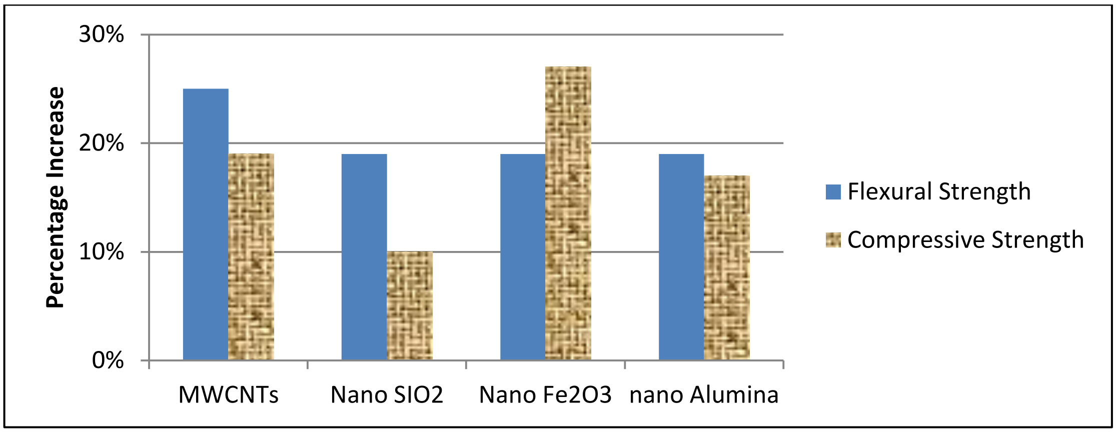

Fig. 1. Strength increase by adding various nano-materials to the concrete mix [1].

Konsta-Gdoutos et al. (2010) [13] noticed large aggloromates and bundles when using nano materials in concrete without using dispersing agents. These aggloromates decrease the linkage of nano particles with the binding phase of concrete. In order to enhance the bonding and to increase the nano materials dispersion, it is recommended to add super plasticiser, and ultrasonification [8, 18–20].

Vishwakarma et al. (2016) [4] used nano-particles size (~50-70 nm) of Rice Husk Ash (RHA) agricultural waste as a partial replacement of Ordinary Portland Cement. Combustion of rice husk at controlled temperature was used to obtain RHA. The compressive strength, split tensile strength and flexural strength tests showed Rice husk ash modified concrete (RHAC) has higher strength than the fly ash modified concrete (FAC) due to the presence of nano-silica.

2.3. Nano-Technology and Sustainable Construction

Eco-innovation in nano-construction is still concentrating more on potentialities rather than actual developments.

According to Kutschera et al. (2009) [21], the main driving force in the construction industry is to adopt new technologies aiming to reduce energy and CO_2 emissions during the construction process as well as whilst the buildings utilization. This energy reduction and/or preservation of natural resources can be achieved through creating new nano-structured materials with extended durability.

Bhuvaneshwari, B. et al. (2011) [2], conducted some nano-research on broad application opportunities which addressed almost all aspects of construction. The study illustrated that great variety and scope of the many emerging nano-technological areas provided interesting solutions that pointed to novel climate solutions for achieving resource efficient and intelligent buildings and cities. Many of these solutions can be applied in existing buildings where the climate potential is considerable; e.g. via surface treatments, applications of thin panels and high efficient insulation. The study presented some results extracted from the recent two green construction reports that discussed the barriers for development of green nano-construction. The reports focused on four main areas:

i. Knowledge of nanotech opportunities in the construction sector is inadequate.
ii. The reluctance of the construction sector towards radical innovation.
iii. Some nanotechnologies are expensive
iv. The concern of the market and public towards nano-risks

In order to meet energy requirements of LEED, new insulating materials and smart glazing were produced. For example, a nano-modified concrete was made as a wall that can be potentially be used as a thermal insulator or conductor of temperature to reduce the energy load required for building interior conditioning [3].

Hincapié et al. (2015) [5] conducted a study to understand the flow of engineered nano-materials (ENMs) in the construction and demolition waste (C&DW) streams. The study aimed to gather adequate knowledge about current nano-material applications and assumptions about their market penetration in the Swiss construction sector. The research focused on the flow of ENM in paints used to cover stone or masonry walls and managed to identify the major knowledge gaps in this area which were: the actual uses and stocks of ENM in construction applications, their market share and penetration, their usage life, ENM transformation / degradation /elimination during use and end-of-life phases. This research formed a qualitative basis for more dynamic modelling of all the ENMs in the construction waste stream. The preferred time for potential release from the technical compartments is when waste is treated during recycling and land filling. The study recommended that the same type of analyses must be performed for other products, like cement based and/or insulation materials.

3. Case Study

3.1. Materials and Specimens

The case study depends on local Egyptian materials such as cement, natural sand and saw gang granite waste. The used Portland cement has specific gravity of 3.15, fineness of 9% passing from sieve170, initial setting 2 hrs and final setting 3hrs 12 minutes. Natural sand with a maximum size of 4.75 mm was used.

A by-product gang saw granite waste type was used. The granite waste was dried up by kept it on oven at a temperature of 200°C for 6 hours. The granite powder was weighed before and after drying, the difference of weight should be less than 10% to insure minimum water content. Clean tap water - temperature of was maintained between 20-30°C - was used to produce the concrete mixes. The nano-granite fine powder with particles passed through sieve no. 300 was dissolved in water to form a solution. This solution was added to the other mix components to produce the green concrete mix.

Specimens of 50×50×50 mm mortar cube were used. After mixing process, mixtures were cast in the cube moulds and kept for 24 hours, then; the specimens were cured in curing basins for 28 days.

3.2. Design Mixes

Design mix for cement mortar was prepared by partially replacing cement or sand or both of them with different percentages by weight of nano-granite waste. The first mix prepared was a control mix with 0% replacement of granite waste. The second mix was a cement replacement of 5%by granite waste. The third mix was sand replacement of 10% by granite waste. The last mix was prepared using 5% cement replacement and 10% sand replacement together. A constant W/C of 0.5 was used. Table 1 presents the four series of concrete specimens and their components that prepared for this study.

Proportions of replacement were selected based on the results of previous studies that carried out by Allam et al. (2014 and 2016) [22, 23] that concluded that 5% cement replacement and 10% sand replacement of granite waste gave the best mechanical properties of the mixes.

Table 1. Mixtures components (gm).

Design Mix			**Components Quantity (gm)**				**W/C Ratio**	**Slump Test Results (Cm)**
No	**Name**	**Description**	Cement	Fine Agg.	Granite waste	Water		
1	CM	Control Mix	281.3	843.8	0.0	140.6	0.5	7.8
2	NC5	Nano-Sawgang Granite 5% Cement Replacement	267.2	843.8	14.1	133.6	0.5	6.9
3	NF10	Nano-Sawgang Granite 10% Sand Replacement	281.3	759.4	84.4	140.6	0.5	5.7
4	NC5+NF10	Nano-Sawgang Granite 5% Cement + 10% Sand Replacement	267.2	759.4	98.4	133.6	0.5	5.4

DOI:10.4186/ej.2017.21.4.217

3.3. Laboratory Tests

For the granite waste, two tests were conducted: chemical analysis test and Particle size Analysis in order to identify the chemical and physical properties of the waste material used. In order to study the effect of using nano-granite waste on the concrete properties, a compressive strength test was carried out for concrete mixes at the age of 28 days. After that, a Scan Electron Microscope (SEM) test was conducted to investigate the resulting mortar on a micro structural scale.

3.3.1. Chemical analysis

Table 2 presents the chemical analysis for granite waste samples that carried out in order to identify their chemical characteristics.

Table 2. Results of granite waste chemical analysis.

Main constituents	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**SO_3**	**Ci**	**LOI**
Wt. %	59.58	0.37	13.01	9.77	0.17	0.29	3.8	5.92	4.76	0.07	0.33	0.09	1.56

3.3.2. Particle size analysis

A waste granite solution is sonicated using a bath sonicator, produced by FACL instruments, for 5 minutes. The solution is then analysed using Master Sizer 3000 to show the particle size distribution as illustrated in Fig. 2. The waste granite has an average particle size of 19 to 162 nm as shown in Fig. 2. From the particle analysing it is shown that the sample has D10 = 19 nm, D50 = 51.5 nm, D90 = 162 nm. Where, D10, D50, D90 are the characteristic diameters of the grain size distribution such that 10%, 50% and 90% of the particles is finer.

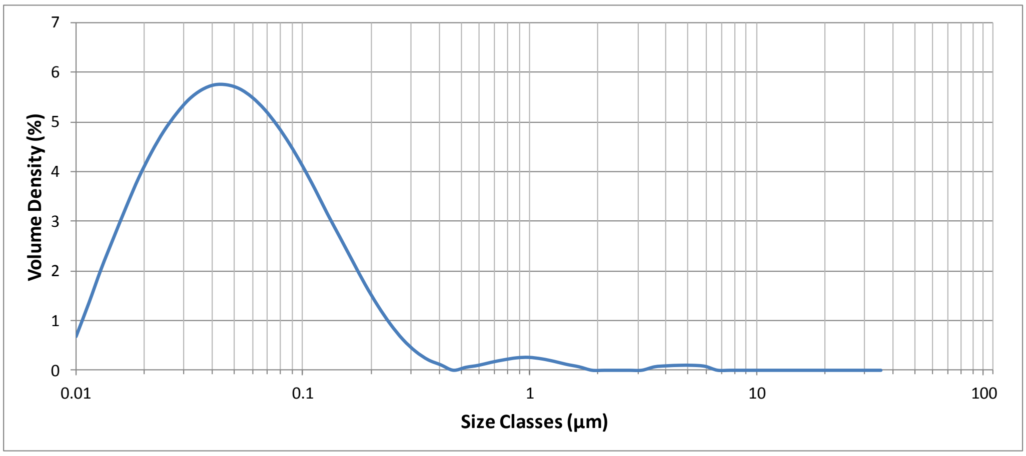

Fig. 2. Particle size distribution.

3.3.3. Compressive strength test

The compression test at curing times of 28 days was carried out on the concrete mixes in order to study the mechanical behaviour of concrete prepared using nano-granite waste particles. Results obtained are reported in Table 3.

Table 3. Results of compressive strength test.

Mix	**CM**	**NC5**	**NF10**	**NC5+ NF10**
Compressive Strength (kg/cm²)	263	349	365	372

Figure 3 demonstrates the relation between 28 days compressive strength values and the proportions of nano-granite waste used in mortar mixtures. The figure shows that:

Using 5% of nano-granite waste as a replacement of cement (NC5), the compressive strength increases by 33% compared to the control mix.

The compressive strength increases by 39% compared to control mix when using 10% of nano-granite waste as a replacement of sand (NF10).

Replacing cement and sand with 5% and 10% respectively with nano-granite waste, (NC5+NF10) increases the compressive strength by 41% compared to the control mix.

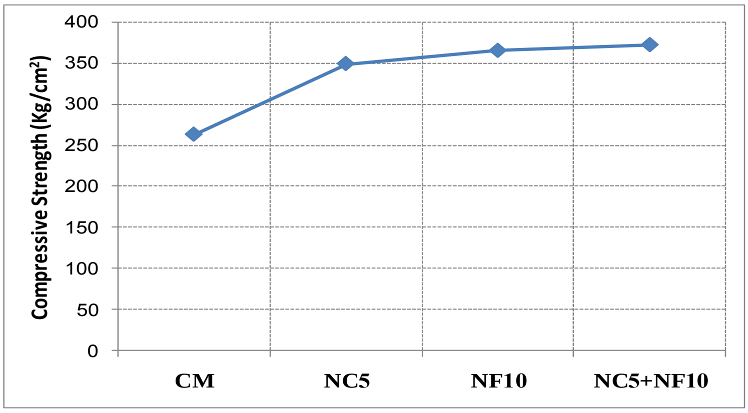

Fig. 3. Relation between compressive strengths.

From the figure, it is shown that the compressive strength increased by adding the nano-granite waste solution to the mix. Three main components of the granite waste SiO_2, Al_2O_3, and Fe_2O_3 shown in the chemical analysis (Table 2) increased the strength of the green mortar when used in the nano scale. The nano Silica particles filled the nano-voids between cement grains, and enhanced the hydration process of cement due to the large reactive surface area. It also reacted with Calcium Hydroxide forming Calcium Silicate Hydrategel (C-S-H), which is the main bonding component responsible for strength in concrete. This conclusion was reported by Garboczi (2009) [7], Belkowitz and Armentrout (2009) [11], and Sanchez and Sobolev (2010) [6]. Furthermore, Nazari et al. [15, 16, 17] showed that by partial replacement of cement with nano Fe_2O_3 and Al_2O_3 particles, the flexural and compressive strengths of concrete increase.

3.3.4. Scan electron microscope (SEM)

Scanning Electron Microscope (SEM) is used to investigate the microstructure of concrete by examining the Inter-facial Transition Zone (ITZ) of the concrete samples at micro-structural level. This zone is considered the weakest zone in the sample hence this examination helps understand and interpret the mechanical properties of the concrete mixtures under study. SEM also investigates the pores or voids inside concrete specimens and this helps to assess the concrete samples porosity.

Samples of about 20 x 20 x 10 mm (depth ±5 mm) were obtained from the selected mortar specimens and their microstructure was examined using Scanning Electron Microscope (SEM). The sections were prepared first by polishing and then coated with conducting material, gold layer, to improve the conductivity of electrons in order to get desired images. The apparatus used in this scanning is Quanta FEG 250.

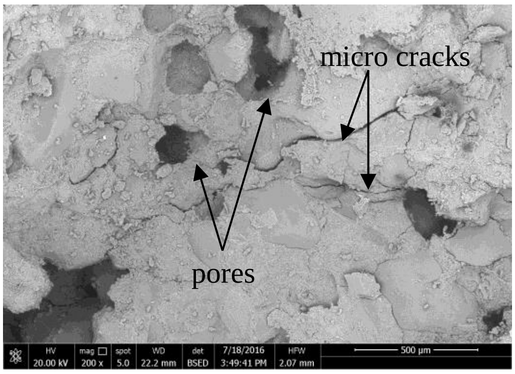

Fig. 4(a). SEM for CM mix.

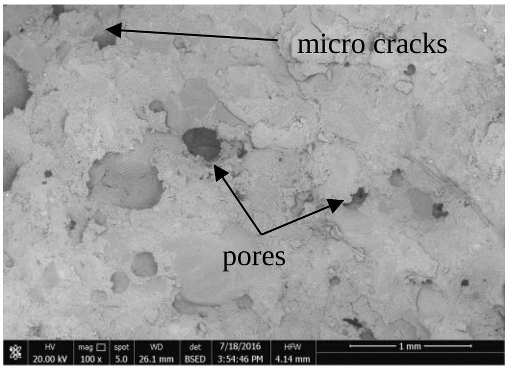

Fig. 4(b). SEM for NC5 mix.

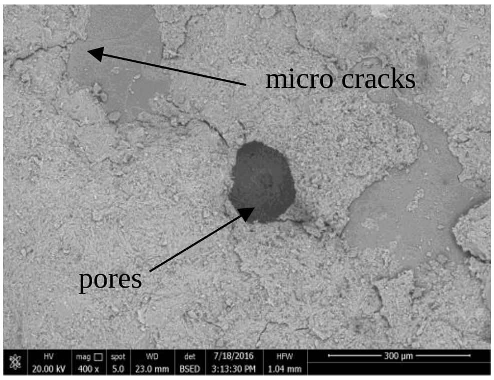

Fig. 4(c). SEM for NF10 mix.

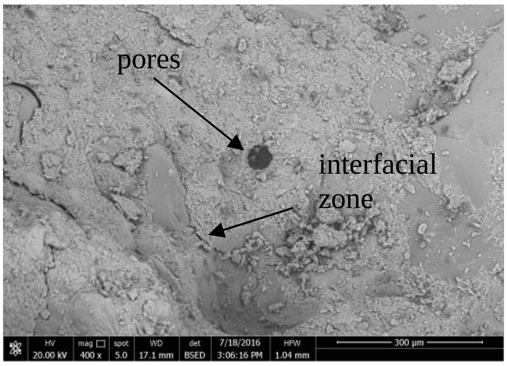

Fig. 4(d). SEM for NC5+NF10 mix.

The SEM image or micrograph of control mix (CM) at 200X magnification (Fig. 4(a)) showed large amount of pores and micro cracks in and around the interfacial zone which can be clearly seen across the voids expressing weak points.

Figures 4(b) and 4(c) present the SEM image of (NC5, NF10) and it is clear that the microstructure of these mixes have denser and homogeneous profile with less micro cracks than that shown in the control mix and this reflects the enhancement found in the compressive values of (NC5)and (NF10) .

The SEM image or micrograph of control mix (NC5+NF10) mix is shown in (Fig. 4(d)) with the minimum micro cracks and maximum density among all mixes and consequently it has the highest compressive strength value. This could be referred to the additional pozzolanic reaction done between existing nano granite particles and calcium hydroxide forming more C-S-H which is considered the main component responsible for strength in concrete products.

The SEM images of NC5+NF10 mix also shows minimum number of pores compared to that of the CM mix large sized pores indicating enhancement in durability properties of cement mortar produced.

4. Comparative Study

As markets are full of uncertainty towards new technologies, the application of nanotechnology is expected to face challenges in terms of environmental, social and economic fields.

A comparative study between green mortar (using nano-granite waste replacement) and traditional mortar was carried out using sustainability indicators to examine the environmental, social and economic changes. A unit of one cubic meter of mortar was used for comparison reasons. The main purpose of this comparison is to present the advantages of using nano-granite waste in cement mortar mixes aiming to maintain sustainable development in the construction industry.

Portland Cement Association (PCI) report by Marceau et al. (2007) [24] stated that the production of one ton cement consumes 4354MJ and produces 906 Kg CO_2. As per the mixture proportions used in the case study, one cubic meter of traditional mortar consumes 550 Kg cement and 1650 Kg sand. While, one cubic meter of green mortar (NC5+NF10) consumes 523 kg cement, 1485 kg sand and 193 kg waste granite.

Based on the above quantities, Table 4 presents the sustainable comparison between green and traditional mortar as a tangible benefit offered by the application of nano-technology in the field of green building products. In the environmental and social fields significant saving was recorded in the field of resource consumption of 10% whereas savings in energy consumption and CO_2 emissions reached 5%. In the economic field, a saving of 6.5% when using green mortar was recorded. Although the benefits shown were not remarkable, it still shows promising signs of reaching a cleaner environment in further attempts of using nano-technology in the construction industry.

Table 4. Comparison between green and traditional mortar.

	For 1 m³ mortar		Green mortar(NC5+NF10)	Traditional mortar	Comparison Percentage
Environmental & Social	Resource consumption	Sand and cement components	Use less raw materials Total of 2008 kg	Use more raw materials Total of 2200 kg	Save about 10%
	Energy consumption	Cement industry	Consume less energy 2275 MJ	Consume more energy 2395 MJ	Save about 5%
	Air Pollutant		Less CO_2 emissions 473 Kg CO_2	More CO_2 emissions 498 Kg CO_2	Save about 5%
	Land use	Granite waste	Reduce land fill 193 kg waste granite	No reduction of land fill	-
	Recyclability		Use recycled content 15%	No recycled contents used	-
Economic	Cost	Mixture (material)	Less initial cost (less cement, less sand, granite waste has no cost) 465 LE	More initial cost (more cement, more sand, no granite waste) 498 LE	Save 6.5%
	Locality	Materials	Use local materials (cement, sand, granite waste)	Use local materials (cement, sand)	-

5. Conclusion

In the field of sustainable construction development, Nanotechnology has a significant effect that it can save energy and reduce resource consumption, waste as well as carbon emissions. When focusing on nano-materials for greener buildings, cement mortar should be considered because it is an important building component in construction industry.

The case study of using nano granite waste in cement mortar mixtures presents promising results for enhancing the rate of hydration ,compressive strength and durability of cement mortar due to the presence of nano Silica, nano Al_2O_3, nano TiO_2 and nano Fe_2O_3 in the correct proportions and methods. Replacing cement and sand with 5% and 10% respectively with nano-granite waste, (NC5+NF10) increases the compressive strength by 41% compared to the control mix indicating an excellent jump towards sustainable construction.

The SEM images reinforce the compressive strength results of the different cement mortar mixes. The results indicate that NC5+NF10 mix, which possess maximum compressive strength has minimum micro cracks and maximum density among all mixes. . The SEM images of NC5+NF10 mix also shows minimum number of pores compared to that of the CM mix large sized pores indicating enhancement in durability properties of cement mortar produced.

The comparative study indicated that, in the environmental and social fields significant saving was recorded in the field of resource consumption of 10% whereas savings in energy consumption and CO_2

emissions reached 5%. In the economic field, a saving of 6.5% when using green mortar was recorded. Although the benefits shown were not remarkable, it still shows promising signs of reaching a cleaner environment in further attempts of using nano-technology in the construction industry.

References

[1] R. Gammampila, P. Mendis, T. Ngo, L. Aye, A. S. Jayalath, and R. A. M. Rupasinghe, "Application of nano materials in the sustainable built environment," in *International Conference on Sustainable Built Environment* (ICSBE-2010), 2010.

[2] B. Bhuvaneshwari, S. Sasmal, and N. R. Iyer, "Nanoscience to nanotechnology for civil engineering: proof of concepts," in *Proceedings of the 4th WSEAS International Conference on Recent Researches in Geography, Geology, Energy, Environment and Biomedicine (GEMESED'11)*, 2011, pp. 230-235.

[3] V. K. Ganesh, "Nanotechnology in civil engineering," *European Scientific Journal*, vol. 8, no. 27, 2012.

[4] V. Vishwakarma, D. Ramachandran, N. Anbarasan, and A. M.Rabel, "Studies of rice husk ash nanoparticles on the mechanical and microstructural properties of the concrete," *Materials Today: Proceedings*, vol. 3, no. 6, pp.1999-2007, 2016.

[5] I. Hincapié, A. Caballero-Guzman, D. Hiltbrunner, B. Nowack, "Use of engineered nano-materials in the construction industry with specific emphasis on paints and their flows in construction and demolition waste in Switzerland," *Waste Management*, vol. 30, no. 43, pp. 398-406, 2015.

[6] F. Sanchez and K. Sobolev, "Nanotechnology in concrete—A review," *Construction and Building Materials*, vol. 24, pp. 2060-2071, 2010.

[7] E. J. Garboczi, "Concrete nano-science and nanotechnology: Definitions and applications," in *3rd International Symposium on Nanotechnology in Construction*, Prague, Czech Republic, 2009, pp. 81-88.

[8] K. Sobolev, I. Flores, L. M. Torres-Martinez, P. L.Valdez, E. Zarazua, and E. L. Cuellar, "Engineering of SiO_2 nanoparticles for optimal performance in nano cement-based materials," in *3rd International Symposium on Nanotechnology in Construction*, Prague, Czech Republic, 2009, pp. 139-148.

[9] P. Hosseini, A. Booshehrian, M. Delkash, S. Ghavami, and M. K. Zanjani, "Use of nano-SiO_2 to improve microstructure and compressive strength of recycled aggregate concretes," in *Nanotechnology in Construction 3*, 2009, pp. 215-221.

[10] J. Vera-Agullo, V. Chozas-Ligero, D. Portillo-Rico, M. J. García-Casas, A. Gutiérrez-Martínez, J. M. Mieres-Royo, and J. Grávalos-Moreno, "Mortar and concrete reinforced with nanomaterials," in *Nanotechnology in Construction 3*, 2009, pp. 383-388.

[11] J. S. Belkowitz and D. Armentrout, "An investigation of nano silica in the cement hydration process," in *Masters Abstracts International*, 2009, vol. 48, no. 3.

[12] G. Y. Li, .P. M. Wang, and X. Zhao, "Mechanical behavior and microstructure of cement composites incorporating surface-treated multi-walled carbon nanotubes," *Carbon*, vol. 43, no. 6, pp. 1239-1245, 2005.

[13] M. S. Konsta-Gdoutos, Z. S. Metaxa, and S. P. Shah, "Multi-scale mechanical and fracture characteristics and early-age strain capacity of high performance carbon nanotube/cement nanocomposites," *Cement and Concrete Composites*, vol. 32, no. 2, pp. 110-115, 2010.

[14] A. R. Jayapalan, B. Y. Lee, and K. E. Kurtis, "Effect of nano-sized titanium dioxide on early age hydration of Portland cement," in *Nanotechnology in Construction 3*, 2009, pp. 267-273.

[15] A. Nazari, S. Riahi, S. Riahi, S. F. Shamekhi, and A. Khademno, "The effects of incorporation Fe_2O_3 nanoparticles on tensile and flexural strength of concrete," *Journal of American Science*, vol. 6, no. 4, pp. 90-93, 2010.

[16] A. Nazari, S. Riahi, S. Riahi, S. F. Shamekhi, and A. Khademno, "Influence of Al_2O_3 nanoparticles on the compressive strength and workability of blended concrete," *Journal of American Science*, vol. 6, no. 5, pp. 6-9, 2010.

[17] A. Nazari, S. Riahi, S. Riahi, S. F. Shamekhi, and A. Khademno,"Mechanical properties of cement mortar with Al_2O_3 nanoparticles," *Journal of American Science*, vol. 6, no. 4, pp. 94-97, 2010.

[18] T. Kowald and R. Trettin. "Improvement of cementitious binders by multi-walled carbon nanotubes," in *Nanotechnology in Construction 3*, 2009, pp. 261-266.

[19] S. P. Shah, M. S. Konsta-Gdoutos, Z. S. Metaxa, and P. Mondal, "Nanoscale modification of cementitious materials," in *Nanotechnology in Construction 3*, 2009, pp. 125-130.

[20] A. Cwirzen, K. Habermehl-Cwirzen, L. I. Nasibulina, S. D. Shandakov, A. G. Nasibulin, E. I. Kauppinen, P. R. Mudimela, and V. Penttala, "CHH cement composite," in *Nanotechnology in Construction 3*, 2009, pp. 181-185.
[21] M. Kutschera, T. Breiner, H. Wiese, M. Leitl, and M. Bräu, "Nano-modification of building materials for sustainable construction," *Nanotechnology in Construction 3*, 2009, pp. 275-280.
[22] M. E. Allam, E. S. Bakhoum, and G. L. Garas, "Re-use of granite sludge in producing green concrete," *ARPN J Eng Appl Sci*, vol. 9, no. 12, pp. 2731-2737, 2014.
[23] M. E. Allam, E. S. Bakhoum, H. Ezz, and G. L. Garas,"Influence of using granite waste on the mechanical properties of green concrete,"*ARPN J EngApplSci*, vol. 11, no. 5, pp. 2805-2811, 2016.
[24] M. Marceau, M. A. Nisbet, and M. G. Van Geem, "Life cycle inventory of portland cement concrete," Portland Cement Association, 2007.