Nanotechnology for Energy Efficient building Materials Embodied Energy for the Cement Based Building Materials

Fatma Ahmed Elbony
Architecture Department, El-Gazeera High Institute for Engineering, Fatma_bony@yahoo.com,
Sami Sedhom Gad
Architecture Department, El-Gazeera High Institute for Engineering, sami_sedhom@yahoo.com

Abstract:
In the context of increasing the need to advance more energy efficiency in buildings, embodied energy for building materials consideration increasingly significant. Embodied energy of building materials represent an important proportion of the whole energy consumed in the building through its lifecycle. Cement as a key binder in concrete, is an energy-intensive substance and one of the biggest carbon dioxide producers in the environment. Nanotechnology is a great scientific progress which promises a great reduction in energy and use less raw materials. The main aim of this review paper is to present a state-of-the-art potential contribution of nanotechnology to reduce the embodied energy of the cement based building materials whether through the manufacture process; (Initial embodied energy) or by increasing the durability of concrete which associated to its life cycle; (Recurrent embodied energy). Therefore the paper firstly, presents a literature review of the concept of energy efficiency of building materials, with respect to the embodied energy of cement based building materials, highlighting the production energy and the durability of the materials; then reviews the cement based building material (concrete); and finally discusses comparatively between the conventional and the nano cement based materials, the implications of using nanotechnology on the cementitious materials' embodied energy. Literature review showed that, nanotechnology can reduce embodied energy in two ways: first; incorporating nanomaterials such as zinc oxide nano-powder into the cement row mix, resulting in a reduction in both production energy used (initial embodied energy) and greenhouse gases emissions, and second; using nanotechnology helps in the production of more durable cement based materials which contributes to lower building maintenance (Recurring Embodied Energy)

Keywords:
Building Materials, Cement Based Materials, Embodied Energy, Environmental Impacts, Nanotechnology

Paper received 10th April 2021, Accepted 16th June 2022, Published 1st of July 2022

1. Introduction

The embodied energy of a structure has traditionally received little attention in the construction industry since it is little in comparison to the building's operational energy during its life cycle.

It has proven that when operational energy decreases, the fraction of embedded energy (which includes energy required for maintenance) becomes more significant. The cumulated operational energy take many years to equal the cumulative embodied energy, it is depending on the building efficiency and the operation energy. Figure 1 shows an office building in Australia, where it may take 50 years of low level operation to achieve the same total quantity of cumulative energy as the embodied energy [1].

Embodied energy is described as "the energy spent by all processes involved in the manufacture of building materials and components, as well as all activities required to support the construction process." It may be divided into two parts; direct and indirect energy requirements [2]. In other words as will be discuss later; it may be divided into initial embodied energy, and recurrent embodied energy

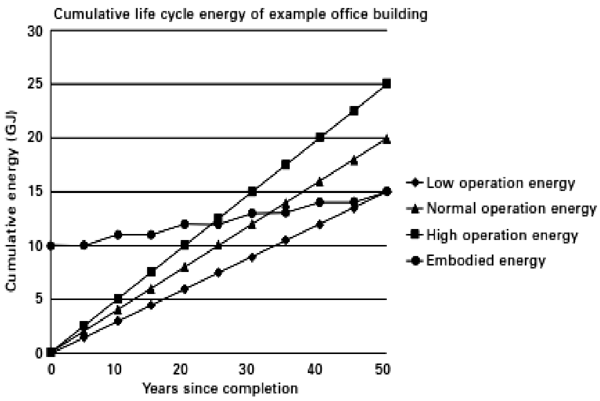


Fig. 1. A comparison of office building's total life cycle energy [1].

Embodied energy accounts for a significant portion of the total building energy consumption, since as a global average, it is estimated that 50–60% of the world's annual energy production is used by the industries of the built environment of which 36% is consumed directly in the operation of buildings, then consequently there is about 14 and 24% is embodied in the buildings and materials themselves. In some cases, it is found that, the yearly operating energy usage is ten to twenty times the embodied energy use [2]

There are many aspects affecting the building materials' embodied energy; firstly the extraction of the row materials, trans these materials to the manufacture, the manufacturing process and the amount of energy consumed, and finally the durability of the building material which influence the maintenance energy consumption and increase the life cycle of the building and consequently reduce relatively the embodied energy, since it is well known that the high durability of the building materials the less proportion of the embodied energy. From another viewpoint, the recyclable building material contributes to reduce the embodied energy [3].

According to the literature review, nano technological advancements have a significant contribution in the building energy conservation aspects, particularly through the enhancement of the building materials which consequently affecting the operational energy of the building. The recent development in nanotechnology provides ample opportunities for the building materials to be more energy efficiently through the reduction of its embodied energy.

Cement based materials, despite their widespread usage, have weak mechanical qualities and are extremely permeable to water. Portland cement, the major binder of concrete, is accounts for about 80% of all CO2 emissions from concrete, which accounts for 6% to 7% of the total CO2 emissions in the world [3]. In this context, the primary goal of this study is to discuss the potential contribution of nanotechnology to reduce the embodied energy of the cement based building materials through two aspects:

1) The manufacture process; reduce the energy consumption for Portland cement manufacturing (production energy) as the main binder of concrete
2) Increasing the durability of concrete which associated to its life cycle.

Problem

Embodied energy of building materials represent an important proportion of the whole energy consumed in the building through its lifecycle, according to the literature review, over a 25-year period, the energy embedded in a structure may account for as much as 67 percent of its operational energy [4]. Portland cement production accounts for about 2% to 3% of world's primary energy consumption and emits a significant quantity of CO2 (approximately 1 ton per ton of clinker) [5]. Moreover, cement based materials have weak mechanical qualities and are extremely permeable to water.

Objective

The main aim of this review paper is to present a state-of-the-art potential contribution of nanotechnology to reduce the embodied energy of the cement based building materials whether through the manufacture process; (Initial embodied energy) or by increasing the durability of concrete which associated to its life cycle; (Recurrent embodied energy)

This aim achieved through three steps:

- Review the cement based building material (concrete) as the most used material in the world;
- Discuss the building materials' embodied energy generally and in particular for the cement based materials as a recent problem face the energy efficiency of buildings.
- Highlight through a comparison between the conventional and the nano cement based materials, the implications of using nanotechnology on the cementitious materials' embodied energy.

Research methodology

The research methodology is based on literature review and comparative analysis

- Literature review is for;

1) Studying the concept of energy efficiency of building materials. The research focused on the embodied energy of cement based building materials, highlighting the production energy and the durability of the materials.
2) Review the implications of using nanotechnology to improve the durability of cement based materials

- Comparative analysis is carried out between the conventional cement base building materials and the nanotech cement products from the view point of embodied energy (initial and recurrent embodied energy); to get recommendations and highlight the effectiveness of implementing nanotechnology to achieve energy efficient building materials.

Significance

Several studies have been discussed the embodied energy of building materials in order to improve building energy efficiency. This paper focuses on reviewing the effect of using nano-based materials on the embodied energy of cement-based materials which represent the most building material used worldwide.

2. Building Materials

Throughout their life cycle, building materials have an impact on both the built and natural environments. The pre-use phase of a building relates closely to the material life cycle, it includes the extraction of raw materials, manufacturing process, delivery to the construction site, installation on site, and additional materials necessary throughout the operating stage for maintenance, refurbishment and renovation. These processes require significant inputs of energy.

Manufacturing may have negative effects on the environment, including contamination of the air, water, and ground. Manufacturing also needs energy, which is mostly generated from fossil fuels and is linked to climate change and pollution [6]. It is stated that, energy efficient building materials should be developed and manufactured to be long-lasting and low maintenance throughout the duration of their useful lives.

2.1 Building Materials and Energy

The energy used up by the building construction is not limited by the amount needed for the building's operation stage (operation of mechanical and electrical installation for cooling, heating, lighting,..), but it also includes the amount of energy used through the manufacturing of the building materials and components, the energy needed through the building's construction phase and replacement, maintenance and deconstruction phase.

The huge quantities of construction materials generated every year require 2–3 percent of the world energy, and about 12–15 percent of the energy used in industry. Furthermore, there is a growing recognition that current concrete manufacturing and building techniques are unsustainable [3].

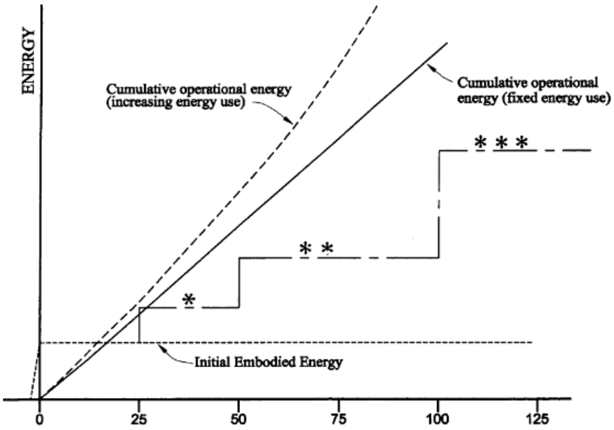
The energy required for the manufacture of building materials and components includes the energy required for the extraction of raw materials and transportation to the manufacturing facility. These amounts of energy hidden in building materials and associated with the construction process are referred to as "embodied energy."

2.2 Building Materials' Embodied Energy

Embodied energy is described as "the energy consumed by all processes connected with the manufacturing of building materials and components, as well as all activities required to support the process." There are three approaches to this dentition: energy used from raw material extraction to factory gate (cradle to gate), energy consumed for transporting materials to site works (cradle to site), and energy consumed from extraction to destruction and removal (cradle to grave).

The production energy accounts for 85 to 95 percent of the total energy of matter, (The remaining 5 to 15 percent is connected to the construction, maintenance, and destruction of the structure.) [7].

Over the course of 50 years, a building's



BUILDING LIFE (years)

Fig. 3. Building's life operational and embodied energy. * Over a period of 25 years, the total embodied energy and the recurrent embodied energy, fifty years**, and a hundred years***. A, Construction Phase; B, Operation Phase [4].

embedded energy is estimated to account for between 6 percent and 25 percent of overall energy consumption [8]. It could be split into two parts:

1) The initial Embodied Energy which consumed in the beginning of the building material's life cycle, it rises from zero to maximum occurs throughout the construction phase. Construction energy is considered to be included in the original embodied energy.
2) Recurrent Embodied Energy is the energy consumed due to maintenance, renovation, and refurbishment of building materials, components, or systems during its lifetime. The durability and upkeep of building materials, systems and components installed in the building, as well as the building's life duration, all impact recurrent embodied energy.

As shown in Figure 3 the initial embodied energy grows from zero to a maximum through the construction phase. The rise in embodied energy throughout the operating phase is due to repainting, lighting and system replacement, and refurbishing. Despite the fact that these statistics are illustrative and cannot be applied uniformly, they clearly demonstrate the importance of recurring embedded energy in life-cycle energy analysis [4].

According to a study conducted on a 97-unit apartment complex, both in terms of embodied energy and operational energy. It is found that reinforced concrete (concrete + steel) has 70% of the total embodied energy; hence, substantial energy savings can only be achieved by decreasing the energy in this material [7].

2.3 Environmental Impacts of Material use

As well as embodied energy, it is important to think about embodied pollution that occurs throughout the manufacturing of construction materials and components [4]. The amount of energy used in the production of building materials is directly proportional to CO2 (Carbon Dioxide) emissions. Each GJ of embodied energy produces an average of 0.098 tones of CO2. The use of high-energy-intensity building materials contributes to a significant increase in greenhouse gas emissions [9].

2.4 Factors Affecting the Embodied Energy of Building Materials during their Life Cycle

There are several factors that influence the embodied energy of building materials such as, use of durable building materials to reduce the maintenance energy, use local materials to reduce the transportation energy, decrease the manufacturing energy, using renewable energy,

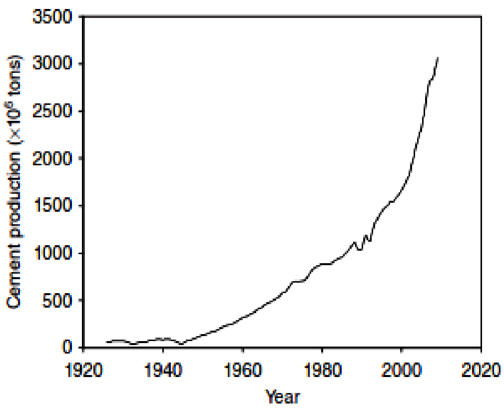


Fig. 4. Global annual cement production from 1925 to 2009 [10].

Natural materials, recycled materials… This review paper is concern about two points; durability and production energy and aims at presenting the-state-of-the-art about the effect of using nanotechnology to reach the following two points:

- Decrease the manufacturing energy
- Increase the durability of building materials

1. Cement Based Materials

Cement is the main material of concrete which is the most building material used worldwide, therefore cement manufacturing and its affect on the energy consumption and consequently on the environment is very vital for the construction industry. Portland cement is produced by heating a combination of limestone and clay, or other materials with a comparable bulk composition and adequate reactivity, to around 1450 degrees Celsius [5].

Cement is being produced in excess of 3 billion tons per year, making it the most commonly utilized solid on the planet, Figure 4 [10]. World production of cement has surpassed 2.8 billion tons per year with 4 billion tons per year predicted by 2050 [11]; accordingly it is crucial to identify methods to make cement more environmentally with less embodied energy whether through the production or the operational energy.

Studies have shown that using energy efficiency technology that is now available on the market and practices in the cement manufacturing across the world may save energy [12]. The purpose of this article is to look at the impact of nanotechnology as a new technique for reducing the manufacturing energy (embodied energy) for concrete, which is the most widely, used cement-based building material on the planet.

3.1 Embodied Energy of Cement Based Materials

Cement industry is under pressure to minimize its energy use as well as its emissions of greenhouse gases. The cement and concert production is an energy intensive process.

1) Initial Embodied Energy (Manufacturing Energy)

Portland cement production consumes around 2% to 3% of world primary energy and emits a significant quantity of carbon dioxide (about 1 tone per 1 tone of clinker) accordingly; it's important to reduce both cement production energy and greenhouse gas emission [5].

Cement manufacturing necessitates that clay and limestone be heated to 1450°C, which necessitates the use of fossil fuels to create that heat, releasing substantial CO2 quantities into the atmosphere in the process. It is estimated that one tone of CO2 is emitted into the atmosphere for every tone of cement produced [10].

Concrete is the second most widely used material on the planet following the water and is utilized as a building material all over the world. Concrete is produced throughout the world at a rate of around annually, 5.3 billion cubic meters. Many new technologies are focusing on alternate materials and techniques to decrease concrete's carbon impact. [13].

Despite concrete is generally requiring low embodied energy as shown in Figure 5, 6; however, the large amount of concrete used in construction sector makes it the largest consumed of energy among all building materials.

Furthermore, the lifespan of concrete constructions is varying from 50 to 100 years, depending on the material characteristics and climatic circumstances [3]. This means that the embodied energy of some kinds of buildings such as office building may equal the operational energy through its life cycle.

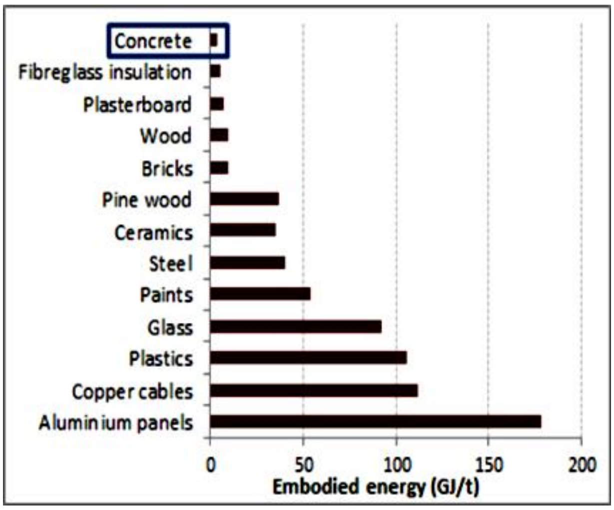


Fig. 5. Comparison of embodied energy of construction materials per ton of product [14].

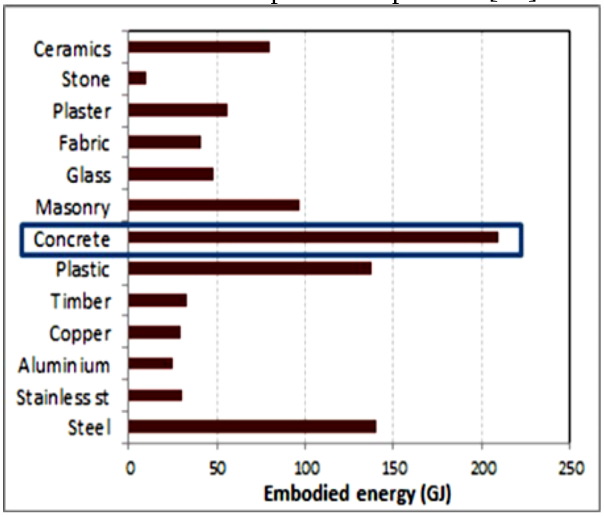


Fig. 6. Embodied energy of construction materials based on their use in building [14].

2) Recurrent Embodied Energy (Manufacturing Energy)

Durability refers to a product's ability to last for an extended period of time without deteriorating significantly. A durable substance benefits the environment by saving resources, minimizing waste, and lowering the environmental effect of maintenance and replacement. The manufacturing of replacement construction materials depletes natural resources and has the potential to pollute the air and water.

Despite their widespread usage, cement-based materials have week mechanical characteristics and are extremely permeable to water and other hostile chemicals, reducing their longevity.

Normal strength concrete generates structures that are less durable and require more regular maintenance and conservation operations, or even total replacement, resulting in greater raw material and energy consumption. The fundamental issue about ordinary Portland cement concrete (OPC) durability of is the material's inherent characteristics, which include a high degree of permeability. This is in addition to the issues created by improper concrete placing and curing procedures [12].

2. Embodied Pollution

The production of construction components, as well as their transportation to the job site, results in embodied pollution [1]. In reality, 1 kilogram of cement produces just 0.6–0.8 kg of CO2 that is small comparing to other materials manufacturing emissions like aluminum or insulating materials [11].

Because of the scale of cement manufacturing, the cement sector has a greater effect than other energy-intensive industries; it is expected that by 2050, demand for Portland cement will have increased by over 200 percent from 2010 levels, reaching 6,000 million tons per year. Recent environmental publications, on the other hand, have expressed worry about the environmental impact of cement and, as a result, cement-based products such as concrete [3].

Cement manufacturing is considered one of the biggest sources of CO_2 in the environment. According to estimates, around 7% of global carbon dioxide emissions are attributed to cement production. The major binder in concrete, Portland cement, accounts for about 80% of the total CO2 emissions connected with concrete [3].

3. Nanotechnology and Building Materials

Nanotechnology is a great scientific progress which promises a great reduction in energy and use less raw materials. Nanotechnology is defined differently by different people, but it typically refers to the study and manipulation of matter at the nanoscale, which ranges from 0.1 to 100 nanometers [15].

One of the most significant benefits of nanotechnology and nano-based building materials is that they are predicted to save energy and conserve resources in two ways through two approaches: The first approach is the operational energy, since nano-based insulating materials can aid in the reduction of energy required for cooling and heating of buildings, nano-coatings with exceptional properties can increase the lifetime (durability) of materials and decease the energy demand for cleaning (maintenance energy). The second one is its potential contribution to reduce the building materials embodied energy represented in the production energy.

4. Nanotechnology for Cement Based Building Materials

Nanotechnology in cement and concrete is primarily utilized to improve physical-mechanical characteristics and provide new capabilities that save significant amounts of material and energy at each step of the product life cycle. Nanotechnology, for example, may be used to evaluate, change, and regulate cement hydration in mortars and concrete, resulting in improved general performance in terms of mass and the ability for achieving outstanding physical, chemical, and mechanical characteristics utilizing fewer resources.

The nano engineering of cementitious materials, which is regarded one of the most promising developments, aims at reduce substance and use of energy, particularly during manufacturing phase (by far the most significant in the cementitious materials life cycle) This goal is achieved by a material design approach that takes two alternative approaches. On the one hand, raw materials can be substituted to reduce the amount of energy necessary through the process of clinker burning; on the other hand, improved mechanical properties can be designed into cements and concretes, reducing the amount of material used and, as a result, energy consumption and pollution.

According to literature review, nanotechnology used to improve the manufacturing of cement and enhance the characteristics of concrete. Nanotechnology has a lot of potential in terms of developing new concrete products, as will be shown later, and materials for minimizing the future environmental effect of cement-based materials. The following are the most significant technological advances in concrete that are most possible to result from nanotechnology's application [16]:

- High-performance concrete materials are being developed for their mechanical and durability properties.
- Sustainable concrete materials and buildings are being developed by lowering energy consumption during cement manufacturing and improving safety;
- Intelligent concrete materials are created by combining nanotechnology-based self-sensing and self-powered materials with cyber infrastructure technologies;
- Novel concrete materials are being developed using nanotechnology-based revolutionary cement and cement paste processes.

The concern of the paper through this part is how nanotechnology has the potential to produce superior materials with improved characteristics and low embodied energy to be used in a variety of applications. It investigates, on one hand the effect of nanotechnology and nanomaterials on the production of Portland cement from the viewpoint of energy consumption and CO2 emissions. On the other hand it investigates the effect on the durability of concrete which associated with the energy required for maintenance and refurbishment of the building.

1. Nanotechnology and the Initial Embodied Energy (Production Energy)

One of the first advantages of nanotechnology is the reduction of energy and raw material consumption in manufacturing process, the development of highly efficient and lightweight materials, the extension of material life, and the improvement of material performance, the reduction of pollution through oxidative catalysis, and the reduction of maintenance costs through the use of self-cleaning and easy-to-clean products [9].

Cement, alternative cementitious binders, and concrete with enhanced performance and lower environmental impact are being developed using nanoscience and nanotechnology. To date the following three areas of research have been identified: [13]

1) Development of nano cements and environmentally friendly, high performance cements/binders produced with less clinker.
2) Incorporation of nanoparticles and chemical admixtures to cement and concrete improves their performance.
3) Using nanoparticles enables for greater utilization of additional cementitious ingredients, lowering energy consumption as compared to Ordinary Portland Cement manufacturing.

For the first and third areas of research; according to a study conducted to investigate the effect of adding nanoparticles of zinc oxide to the cement row mix in order to decrease energy use and CO2 emissions produced during the processing, the percentages of zinc oxide nano-powder that added to the raw material of cement was ranging between 1% and 3%, it has been concluded that, the addition of 1% synthesize zinc oxide nano-powder into Portland cement manufacturing enhances the cement raw mixture burn ability of. The temperature of the clicker was reduced to 1,300°C, compared to 1,450°C–1,500°C usually required, resulting in both reduction in energy consumption and greenhouse gas emissions [17].

According to another study, Zinc oxide has been proven to improve raw mix burn ability, speed clinkerization processes. The addition of 1.5 percent Zn O to the raw mix reduced clinkerization energy from 124 to 52 kJ/mol [18].

5.2 Nanotechnology and the Recurrent Embodied Energy (Durability)

The study RILEM TC 197-NCM, ‘Nanotechnology in Construction Materials,' indicated that using of nanoparticles to enhance the strength and durability of cementitious composites as a research field with high nanotechnology potential [12]. Concrete's durability can be improved by reducing permeability and improving characteristics of shrinking. These effects can be achieved by using nano-modified cements or nano-created paste additives.

1) Permeability

Concrete's permeability has an inverse connection with its durability; the lower the permeability, the higher the durability. From the literature review it is found that [12]:

- Water permeability of concrete is reduced by nano-silica particles (SiO_2). When the amount of nano-silica increasing from 1% to 5%, the water permeability depth is significantly decreased [19].
- A decrease in the permeability of the concrete was found when 4 percent nano-Fe_2O_3 per cement mass was used.
- Concrete permeability was reduced when 45 percent of Portland cement was substituted by GGBFS containing 4 percent nano-TiO_2 per cement mass
- The addition of 1% nano-$CaCO_3$ to concrete enhanced its freezing-thawing resistance and decreased its permeability [5].

2) Improved Shrinkage Properties

Shrinkage can cause cracks in concrete which affect its durability. Nanotechnology enables the analysis, modification, and control hydration of cement in concrete and mortar, resulting in improved general performance. Furthermore, the calcium-silicate-hydrate (C-S-H), produced during the cement hydration process by the interaction of several chemical components, which responsible for physical and mechanical properties such as shrinkage, porosity, permeability, and elasticity – can be modified to improve durability. From the literature review it is found that:

- Addition of nano silica with 6% and 18%, showed volume fractions of high-stiffness C-S-H 38% and 50% respectively [16].
- A composition of 2% nano SiO_2 with the addition of 10% micro-silica enhanced the mechanical strength of concrete and improved durability [20].
- Generally, a significant increase in the mechanical characteristics and durability of cementitious materials may be shown with the inclusion of the most commonly used nanomaterials such as (nano-SiO_2, Al_2O_3, TiO_2, AL_2O_3 $CaCO_3$, etc.), nanotubes and fibers (carbon nanotubes and carbon nano fibers). Table 1 represents a short review about using nanomaterials with the cement based materials and its effect on the material's durability

2.1 Nanotech Cement Products

The application of nanotechnology in concrete is most likely to result in the development of concrete materials via engineering for various unfavorable conditions, as well as a reduction in energy consumption during the cement manufacturing process [13].

6.1 Ultra High Performance Concrete (UHPC)

Concrete, as a traditional building material, may be given new characteristics in terms of workability, strength, and durability thanks to nanoscale binders. Filling the holes in the concrete with silicon dioxide nanoparticles makes it denser and more durable. The majority of ultra high-performance concretes (UHPC) used in contemporary practice and documented in the literature has been made with nano-modifications or nano-based additives Steel fibers, which enhance tensile strength, are also used in ultra high performance/high-strength concrete [30]. The compressive strength of this type of concrete is over 200 N/mm2, which is comparable to steel [30].

When comparing the life cycle implications of ultra-high performance concrete (UHPC) to ordinary reinforced concrete, there is a substantial decrease in material consumption (approximately 6 times lower) and energy consumption (about 40 percent), as well as fewer greenhouse gas emissions (about 50 percent) [31]

The development of cement and concrete's physical and mechanical characteristics allows for thinner load-bearing sections than traditional reinforced concrete structural components, with thicknesses similar to steel construction.

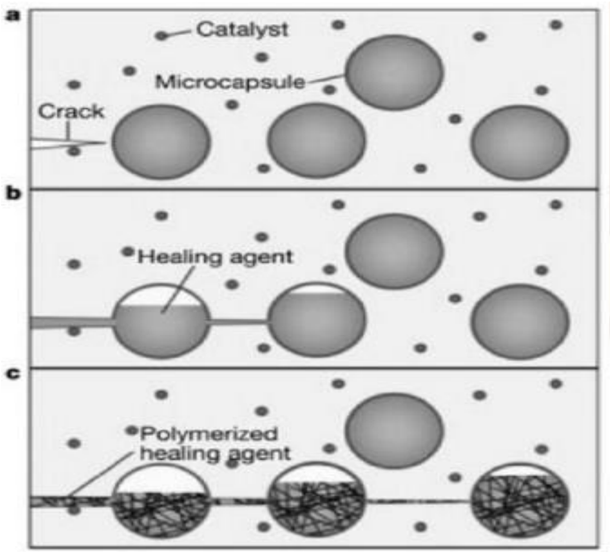


Fig. 7. Mechanism of self healing Concrete [3].

6.2 Self-Healing Concrete

With the cracks of self-healing concrete, imbedded microcapsules burst and, by capillary action, release a healing chemical into the injured area.

When the discharged healing agent comes into touch with an implanted catalyst, it polymerizes and closes the fracture. Self-healing composites regained up to 75% of their initial strength in fracture testing [3]. They have the potential to double or triple the lifespan of structural components, Figure 7.

6.3 Photo Catalytic Concrete

Nanoscale titanium dioxide TiO2 accelerates chemical processes under the influence of ultraviolet radiation and dampness, this process known as Photocatalysis. It is used to make self-cleaning building materials in the construction sector and architecture. The photo catalytic activity of nano-TiO2 when mixed into cement or placed as a coating over concrete aids in the decomposition of organic matter-based filth, which is subsequently washed away when it rains. Richard Meier's study for the Dives in Misericordia church in Rome's white "concrete sails" led to the decision to use titanium dioxide's self- cleaning characteristics to retain the visual properties of the precast curved concrete panels. For a longer period of time, the buildings retain their original appearance [32].

VARIOUS NANOMATERIALS THAT ARE INCORPORATED WITH CEMENT AND THEIR EFFECT ON ITS PROPERTIES [19]

N	Nanomaterials			Effect on property	Reference
1	nano-SiO2	2%		Improving in durability, reducing missions of CO_2, reducing permeability,	[21]
2		6%-18%		Resulted in high-stiffness C-S-H 38% - 50% respectively	[16]
3		4%	Concrete	Decreasing the water absorption (between two and three times lower) in comparison to concrete without nano-silica.	[22]
4	nano-Fe_2O_3	1%–5%	Concrete	nano-Fe2O3 up to 4% improve the compressive and tensile strength, and concrete permeability of water	[23]
5		10%		Maximum values of the compressive strength	[24]
6		4%		Reduction in concrete permeability	[21]
7	nano-Al2O3	2%		Optimum level of nano-Al2O3 particle content was 1.0%	[25]
8		0.25%		Improve the compressive strength of cement-based materials by up to 30%	[26]
9	nano-TiO2	0.1%, 0.5%, 1.0% and 1.5%	Cement paste	Improving the rigidity by 4.52%, 8.00%, 8.26% and 6.71% respectively at 28 days age	[27]
10		1%		Improving concrete mechanical properties	[28]
11	nano-ZrO2,nano-TiO2, nano-Al2O3, nano-Fe3O4	1.5%		Nano-Al2O3 is the most effective material for the durability and mechanical performance of concrete.	[29]

6.4 A Comparison

Table 2 represents a comparison between conventional cement based materials and Nanotech cement products from the viewpoint of embodied energy to highlight the effectiveness of implementing nanotechnology to achieve energy efficient building materials. The comparison concluded three types of nanotech cement products, Ultra High Performance Concrete, Self healing Concrete and Photo Catalytic Concrete, versus conventional concrete. As shown in the table; the nanotech cement products use lower production energy and it is characterized by the long term durability (reducing shrinkage, permeability and increasing strength.

a comparison between embodied energy of the nanotech cement products and the conventional cement based materials (by the researcher)

Embodied Energy	NANOTECH CEMENT PRODUCTS	CONVENTIONAL CEMENT BASED MATERIALS
The Initial Embodied Energy (Production Energy)	Comparing to Ordinary Portland Cement manufacturing, incorporating nanoparticles lowering energy consumption as follows: 1) The addition of 1% synthetic zinc oxide nano-powder to Portland cement manufacturing reduced clinker temperature to 1,300°C instead of 1,450°C–1,500°C, allowing for a reduction in both energy usage and greenhouse gas emissions 2) **Ultra High Performance Concrete (UHPC)** A considerable decrease in material usage (about 6 times lower) and energy consumption (around 40% lower), as well as fewer greenhouse gas emissions (about 50 percent).The development of cement and concrete's physical and mechanical characteristics allows for the reduction of load-bearing sections, with thicknesses closer to steel structures than to traditional reinforced concrete structural parts [16].	1) Portland cement is an energy intensive building material; this is because the large amount produced annually all over the world. It is produced by heating a combination of limestone and clay, or other materials with a comparable bulk composition and adequate reactivity, to around 1,450°C–1,500°C [2] 2) **Conventional Concrete** The manufacture of cement, which is used in concrete, consumes the most energy and has the highest carbon footprint of all the concrete produced. The huge amounts of Concrete generated each year require 2–3% of global energy and 12–15% of industrial energy
Recurring Embodied Energy (Durability of Building Materials)	Nanotechnology enables for the modification and control of cement hydration in mortar and concrete, which improves shrinkage, porosity, permeability, and elasticity - all of which may be improved to produce greater durability. 1) **Ultra High Performance Concrete (UHPC)** The characteristics of ultra-high strength concrete using nano cement was significantly improved. Using nano cement enhanced the long-term durability of concrete by reducing shrinkage, increasing strength, and reducing permeability. . 2) **Self-Healing Concrete** Self-healing composites were able to regain up to 75% of their initial strength in fracture testing. They have the potential to double or triple the lifespan of structural components. 3) **Photo Catalytic Concrete** Nanoscale titanium dioxide TiO_2 contributes in the reduction of recurring embodied energy, since It aids in the decomposition of organic matter-based filth, which is subsequently washed away when it rains, allowing structures to retain their original appearance for a longer length of time.	The mechanical qualities of cement base materials are weak, and the underlying difficulty with ordinary Portland cement concrete (OPC) long-term durability is the material's inherent features, which include a high degree of permeability to water and other harsh substances, reducing their longevity (durability). Normal strength concrete generates structures that are less durable and require more regular maintenance and conservation operations, or even total replacement, resulting in greater raw material and energy consumption.
Environmental Impact	Nanotechnology has the potential to help traditional cement materials overcome major	Cement manufacturing is one of the biggest sources of carbon dioxide in the environment.

	environmental challenges, resulting in lower CO_2 emissions and increased durability	According to estimates, the industry is responsible for around 7% of worldwide CO_2 emissions. Portland cement is accountable for nearly 80% of total CO_2 emissions from concrete, which accounts for about 6–7% of total CO_2 emissions on the planet.

Conclusion

Depending on the literature review; Nanotechnology's applicability in cement-based materials is still in its early stages of development. Otherwise by reviewing both Traditional Cement Based Materials (Concrete) comparatively to Nanotech Cement Products from the viewpoint of Embodied Energy, it is concluded that, nanotechnology potential contribution in reducing embodied energy for Cement based building materials are as follows:

In the context of Initial Embodied Energy (Manufacturing Energy), according to previous studies, it is found, through two researches, that the incorporation of nanomaterials, such as zinc oxide nano-powder, in Portland cement manufacturing can reduce the production energy and accordingly reduce the greenhouse gas emissions.

There is a shortage in the information about the effect of using nanotechnology on the production embodied energy (initial embodied energy), accordingly, research endeavors should be increased for exploring the area of efficient building materials.

In the context of Recurrent Embodied Energy (Durability), Reviewing the effect of nanomaterials on concrete as cement based material; it is found that, using nanotechnology helps in the production of more durable cement based materials which contributes to lower building maintenance as follows:

Nanomaterials in concrete have an efficient reaction in terms of various parameters, including material and energy conservation throughout the life cycle.

Incorporation of nanomaterials help in produce high-performance concrete with reduced permeability and improved shrinkage characteristics and accordingly increased durability, and increase structural member strength while lowering their size.

References

[1] Matthew R. Hall, Materials for energy efficiency and thermal comfort in buildings, Woodhead Publishing Limited, 2010

[2] ick Best and Gerard de Valence, Design and Construction: Building in Value, Elsevier Science Ltd., 2002.
Peter F. Smith, Architecture in a Climate of Change, A guide to sustainable design, Second edition 2005

[3] F. Pacheco-Torgal, M. V. Diamanti, A. Nazari and C-G. Granqvist, Nanotechnology in eco efficient construction, materials, processes and applications, second edition, Elsevier Ltd, 2019

[4] Y.G.Yohanis, Life-cycle operational and embodied energy for a generic single-storey office building in the UK, Centre for Sustainable Technologies, School of the Built Environment, University of Ulster, Newtownabbey, Co. Antrim, BT37 0QB, Northern Ireland, UK, 2001

[5] Xin Wang, Effects of nanoparticles on the properties of cement-based materials, Doctor of Philosophy, Iowa State University Ames, Iowa, 2017

[6] Paola Sassi, Strategies for Sustainable Architecture, Taylor & Francis Inc, 2006

[7] F. Pacheco Torgal, Cinzia Buratti,Siva Kalaiselvam, Claes-Göran Granqvist, Volodymyr Ivanov, Nano and Biotech Based Materials for Energy Building Efficiency, Springer, 2016

[8] Paola Sassi, Strategies for Sustainable Architecture, Taylor & Francis Inc, 2006

[9] Behnaz Amirzadeh Shams, Material-Aware Building Design in Responding to Future Needs, Eastern Mediterranean University, Master of Science in Architecture, azimağusa, North Cyprus, 2014

[10] Fernando Pacheco Torgal Said Jalali, Eco-efficient Construction and Building Materials, Springer-Verlag London Limited 2011

[11] F. Pacheco-Torgal , L. F. Cabeza , J. Labrincha and A. de Magalhães, Eco-efficient construction and building materials, Life cycle assessment (LCA), eco-labelling and case studies Woodhead Publishing Limited, USA 2014

[12] F. Pacheco-Torgal, M. V. Diamanti, A. Nazari and C-G. Granqvist, Nanotechnology in eco-efficient construction, Wood head Publishing Limited, 2013.

[13] Ali Hasanbeigi, Lynn Price, Elina Lin, Emerging Energy-efficiency and CO2 Emission-reduction Technologies for Cement and Concrete Production, China Energy Group, Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Lawrence Berkeley

National Laboratory, 2012
[14] Mohammed Seddik Meddah, Recycled aggregates in concrete production: engineering properties and environmental impact, MATEC Web of Conferences 101, 05021 (2017)
[15] W. Zhu, P.J.M. Bartos and A. Porro Application of nanotechnology in construction. Summary of a state-of-the-art report, Materials and Structures / Matériaux et Constructions, November 2004, pp 649-658 https://www.researchgate.net/publication/226541329_Application_of_nanotechnology_in_construction [accessed March 5- 2022]
[16] Bjorn Birgisson, Anal K. Mukhopadhyay, Georgene Geary , Mohammad Khan, Konstantin Sobolev, Nanotechnology in Concrete Materials, TRANSPORTATION RESEARCH BOARD 2012 EXECUTIVE COMMITTEE OFFICERS
[17] Dalia Ahmed Mohammed Osman, Omer Nur, Mustafa Abbas Mustafa, Reduction of Energy Consumption in Cement Industry Using Zinc Oxide Nanoparticles, Journal of Materials in Civil Engineering, March 2020
[18] García-Díaz, F. Puertas, M. F. Gazulla, M. P. Gómez, y M. Palacios, Effect of ZnO, ZrO2 and B2O3 on clinkerization process. Part I. Clinkerization reactions and clinker composition, Materiales de Construcción Vol. 58, 292, 81-99
[19] Zhang, P.; Li, Q.; Chen, Y.; Shi, Y.; Ling, Y.-F. Durability of steel fiber-reinforced concrete containing SiO2 Nano-Particles. Materials 2019, 12, 2184. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6651140/pdf/materials-12-02184.pdf [accessed March 5- 2022]
[20] Jalal M, Mansouri E, Sharifi pour M, Pouladkhan A Mechanical, rheological, durability and micro structural properties of high performance self-compacting concrete containing SiO2 micro and nanoparticles. Materials and Design, 2012. 34, 389–400
[21] Ozyildirim C, Zegetosky C, Laboratory investigation of nanomaterials to improve the permeability and strength of concrete. Virginia Transportation Research Council, Final Report VTRC 10-R18, 2010
[22] Supit, S.W.M.; Shaikh, F.U.A. Durability properties of high-volume fly ash concrete containing nano-silica. Mater. Struct. 2015, 48, 2431–2445. https://link.springer.com/content/pdf/10.1617/s11527-014-0329-0.pdf [accessed March 5- 2022]
[23] Khoshakhlagh, A.; Nazari, A.; Khalaj, G. E, effects of Fe2O3 nanoparticles on water permeability and strength assessment of high strength self-compacting concrete. J. Mater. Sci. Technol. 2012, 28, 73–82. https://www.sciencedirect.com/science/article/abs/pii/S1005030212600267?via%3Dihub [accessed March 5- 2022]
[24] Fang, Y.; Sun, Y.; Lu, M.; Xing, F.; Li, W. Mechanical and pressure-sensitive properties of cement mortar containing nano Fe2O3. Adv. Eng. Res. 2018, 146, 206–210. http://www.atlantis-press.com/php/paper-details.php?id=25889573 [accessed March 5- 2022]
[25] Nazari A, Riahi S Al2O3 nanoparticles in concrete and different curing media. Energy and Buildings, 2011, 43, 1480–1488
[26] Muzenski, S.; Flores-Vivian, I.; Sobolev, K. Ultra-high strength cement-based composites designed with aluminum oxide nano-fibers. Constr. Build. Mater. 2019, 220, 177–186. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6861922/pdf/materials-12-03548.pdf [accessed March 5- 2022]
[27] Feng, D.; Xie, N.; Gong, C.; Leng, Z.; Xiao, H.; Li, H.; Shi, X. Portland Cement Paste Modified by TiO2 Nanoparticles: A Microstructure Perspective. Ind. Eng. Chem. Res. 2013, 52, 11575–11582. https://pubs.acs.org/doi/pdf/10.1021/ie4011595 [accessed March 5- 2022]
[28] Chunping, G.; Qiannan, W.; Jintao, L.; Wei, S. The e
ect of nano TiO2 on the durability of ultra-high-performance concrete with and without a flexural load. Ceram-Silikáty 2018, 62, 374–381. https://www.irsm.cas.cz/materialy/cs_content/2018_doi/Gu_CS_2018_0033.pdf [accessed March 5- 2022]
[29] Shekari A, Razzaghi M Infl uence of nanoparticles on durability and mechanical properties of high performance concrete. Procedia Engineering , 2011, 14, 3036–3041.
[30] nano werk, Nanotechnology in construction, https://www.nanowerk.com/spotlight/spotid=26700.php [accessed Mach. 5- 2022]
[31] Mattia Federico Leone, Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nano-structured Cement-Based Materials, Leone, J Architec Eng Technol 2012, http://dx.doi.org/10.4172/2168-9717.1000102 [accessed March 5- 2022]
[32] nano werk, Nanotechnology in construction, https://www.nanowerk.com/spotlight/spotid=26700.php [accessed Mach. 5- 2022]