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The Role of Green Concrete Technology in Environmental Protection, Sustainable Development and Reduction of Energy Consumption

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ABSTRACT

Today, with the rise of various constructions around the world, especially the concrete buildings, the production and consumption of cement have also considerably increased. In the cement production, which is an integral part of construction, in addition to the indispensable need for consuming the fossil fuels and energy, large amounts of carbon dioxide gas are annually released as a result of cement production. The increasing movement of construction towards the destruction of ecosystems in different geographical areas and the lack of attention and scientific consideration will lead to serious challenges to the future of the construction industry and the ecosystem of different fields. The use of green concrete on the micro and macro scales can be a key solution to this issue, because the use of cement concrete releases a huge amount of carbon dioxide, which is very inconsistent with the goals of sustainable architecture and structure. The purpose of this study is to investigate the green architecture, sustainable structures and, most importantly, green concrete. The study results show that green concrete is an important issue that has revolutionized the concrete industry. The use of materials such as fly ash, geopolymer concrete, rice husk ash, recycled materials of concrete, slag, casting sand, waste glass, crushed concrete, and wood ash in the manufacture of green concrete can reduce the volume of cement and even aggregates in the concrete, which reduces the greenhouse gas emissions and the use of natural materials which reduces the environmental degradation and environmental pollution.

Keywords: Green concrete, Sustainable development, environment, Cement

1. INTRODUCTION

Attempting to implement the concept of sustainable development in the construction industry, the sustainable construction or green construction tries to preserve the environment while providing for the humans' comfort. The green/sustainable construction represents a new approach to the architecture that is quality-oriented and pays significant deals of attention to the future and the environment. The sustainable construction refers to deep concepts that establish links among the humans, the nature, and the architecture [1]. The environmental pollution-caused problems have turned into an important issue. Most commonly caused by pesticides, herbicides, etc., the environmental pollutions include the water, air, and soil pollutions. These pollutions not only tend to destroy the biodiversity in the environment, but also put the humans' health at risk, The nanotechnology presents numerous advantages for improving the existing environmental technologies and hence formulates new technologies that are better than the existing ones in a number of ways [2]. The thermal energy consumed for cement production is responsible for 15% of total energy consumption by all industries and 3% of total energy consumption of Iran; this is while the concrete freezing is a common problem in cold areas [3]. In Iran, some 26% of the total energy consumption of the country is spent by industries. The electricity, natural gas, and crude oil serve as source for supplying 29%, 60%, and 11% of the energy consumed by the Iranian industries, respectively. Among other active industries in Iran, the cement production and steel manufacturing industries are the two top consumers of energy. Producing a total of 64 million tons of cement at the cost of 7,200 million kWh of electrical energy, the cement production industry consumes some 3% of the total electricity generated around the country, equaling to 9.7% of the total energy consumed by the industrial sector [4]. The ever-increasing use of industrial construction materials have largely contributed to environmental degradation, because the attitudes toward the sustainable development in the construction industry has been largely overseen and the respective policies and decision-makings have failed to follow rational and scientific rules. This is while an unleashed and ever-increasing trend of construction has been evident. In this respect, reasonable utilization of environment-friendly materials can largely contribute to the objectives of the green architecture and construction. Being made up of environment-friendly and biocompatible filling materials, the green concrete is important for not only its great compressional strength and specific weight, but also its principal compatibility with the environment, making it applicable for building various structures and walls (green wall blocks) at both micro and macro scales; these can push ahead the sustainable development and sustainable architecture, in turn. The construction industry has been recognized as one of the largest job-producing industries in the world, where a large number of people are employed at any time. Despite the owners' attitude toward the ever-increasing growth of this industry, a comprehensive, rational, and future-oriented approach, where the environment protection is carefully respected, is, unfortunately, yet to be followed, with nearly any individual involved in this industry strictly seeking for economic benefits by accelerating the construction projects. This is while the production non-biocompatible construction materials tend to boost the disposal of environmental pollutions into the environment. Regardless of the scale, the use of concrete damages the natural ecosystem largely while further impacting the atmosphere adversely upon the emission of greenhouses during the concrete curing process. These outcomes are far away from the objectives followed by the sustainable development and green architecture and construction. Today, the ever-increasing construction of concrete masons have largely added to the production and use of the cement around the world. In order to produce the cement, as a constant material for any construction project, the fossil fuels are inevitably required for generating the needed energy, and this leads to the emission of large volumes of the CO2 gas every year. According to the Kyoto Protocol, where the reduction of CO2 emission to prevent the so-called global warming was greatly emphasized, researchers have looked for appropriate alternatives to replace the cement. In this respect, a number of research works have been performed on the natural and artificial pozzolans as well as geopolymers. In the past, extensive deals of research were performed on the use of agricultural wastes, including the palm, coconut and sugarcane wastes as well as the rice husk. The findings showed that these waste material had potentials for incorporation into the concrete mix. The reuse of the agricultural wastes for preparing concrete mixes not only reduced the dependence on the conventional materials for concrete mix preparation, but also attenuated some of the otherwise adverse impacts on the environment, including the landfilling of the generated waste. Although the use of agricultural wastes degraded particular concrete properties, but it was acknowledged as a novel method for selecting the waste material for preparing the concrete mixes [5].

The research works on the use of agricultural wastes in the concrete production include those in the palm oil industry (e.g. palm oil fuel ash (POFA) [6] and palm kernel shells [7]), coconut industry (e.g. coconut shell waste [8], and coir [9]), and the rice industry (e.g. rice husk [10]). These waste material have been used for concrete production in the form of grains, fibers, and supplemental cement material. Hasemli investigated, with an approach to the environment, the compressive strength of the green concrete containing fly ash and recycled aggregates [11]. Mostofinejad and Gharibi studied the green concrete containing waste industrial ceramics. Their results showed that the use of such waste material not only did not decrease the compressive strength of the concrete, but also increased the compressive strength of the concrete by 40% upon replacing all aggregates with the waste material [12]. Sohrabi presented a review on the cases where agricultural waste material was used to produce green concrete in Iran and some other countries. In this paper, engineering properties (density, slump, compressive strength, etc.) of the agricultural waste materials (e.g. nutshell, pistachio shell, palm shell, etc.) from Iran and Malaysia were analyzed for the production of green concrete [13]. In 2019, Mansoori studied the industrial waste material that could be used to produce the green concrete. In his review paper, he compiled the research works on the use of the industrial waste material for green concrete production as a novel technology [14]. In another work published in 2019, Peyman took a look on a number of credible research works on the green concrete and presented a formulation for manufacturing a green concrete. The paper began with a review on some researches reporting on the green concrete and published by high-rank international journals and then proceeded to propose a new self-compacting lightweight geopolymer concrete [15]. Yazdi et al. investigated some properties of the textile-reinforced concrete, biological concrete, and green concrete. In this study, the advantages and challenges ahead of using recycled material for producing green concrete, textile-reinforced concrete, and biological concrete in the construction industry in Iran and the world were assessed [16]. Dorijani et al. evaluated the compressive strength of a green concrete containing agricultural waste (nutshell). The results indicated a decrease in the compressive strength with increasing the fraction of the nutshell in the studied concrete mixes (i.e. the volumetric ratio of the nutshell in the concrete [17]. In 2018, Ansari and Toosi investigated the mechanical properties of a green concrete wherein the bagasse ash was used to replace the cement. They showed that the workability of the concrete decreased with increasing the bagasse ash to replace the cement in the concrete mix, due to the increasingly higher water intake of the ash compared to the cement [18]. Seifolahi et al. focused on the use of the palm tree wastes for producing the green concrete. Their results indicated that the samples containing the palm leaf ash at 5% exhibited the best performance, as compared to the control sample, so that the obtained compressive and tensile strengths were higher than those of the control sample by up to 35% and 43%, respectively [19].

In 2017, Delnavaz et al. evaluated the compressive strength of a green concrete ample when exposed to the chlorine ion penetration. Their findings indicated that the higher strength of the green concrete samples containing the puzzlegrass ash and the rice husk ash, as compared to the control sample, with the strength improvements being larger for the sample containing the rice husk ash rather than the puzzlegrass ash [20]. Mansoornejad et al. investigated the tensile and compressive strengths of the green concrete samples produced from cement-replacing pozzolan material, municipal wastewater treatment sludge ash, and coal mine waste material. The results indicated that although the replacement of the cement with the wastewater sludge ash and coal ash led to slightly lower strength of the final concrete product, but the concrete was still strong enough for construction purposes [21]. In the present research, the materials used in the production of green concrete and the outcomes of using the green concrete for the sustainable development and environment protection are presented.

2. ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSION IN THE CEMENT INDUSTRY

The cement production is a highly energy-intensive process where 4 GJ of energy is consumed per ton of cement produced. Theoretically speaking, a minimum of 1.6 GJ of thermal energy is required for producing each ton of clinker [22]. Although the average specific energy per ton of produced cement is as low as about 2.95 GJ with state-of-the-art furnaces, some countries spent more than 5 GJ of energy to produce per ton of produced cement [23]. The thermal energy consumed for cement production is responsible for 15% of total energy consumption by all industries and 3% of total energy consumption of Iran; this is while the concrete freezing is a common problem in cold areas [3]. In Iran, some 26% of the total energy consumption of the country is spent by industries. The electricity, natural gas, and crude oil serve as source for supplying 29%, 60%, and 11% of the energy consumed by the Iranian industries, respectively. Among other active industries in Iran, the cement production and steel manufacturing industries are the two top consumers of energy. Producing a total of 64 million tons of cement at the cost of 7,200 million kWh of electrical energy, the cement production industry consumes some 3% of the total electricity generated around the country, equaling to 9.7% of the total energy consumed by the industrial sector [4].

3. SUSTAINABLE DEVELOPMENT

Sustainable development is the development that can respond to the current needs of the organization without compromising the capabilities of the next generation for meeting their needs. This definition recognizes the right of each generation to enjoy the same amount of natural capital as was available to other generations and permitted the use of natural capital to its extent. Sustainable development is an important new perspective in public policy and management which was emerged widely outside the United States. This concept attempts to more clearly consider the future outcomes of current behaviors. Sustainable development addresses various areas: greenhouse gas impacts, climate change, ozone depletion, land degradation, depletion of non-renewable resources, and urban air pollution [24].

3.1 Green architecture

Green architecture or sustainable architecture is one of the new trends and approaches of architecture that has attracted the attention of many contemporary designers and architects in recent years. Derived from the concepts of sustainable development, this architecture is one of the basic needs of mankind in today's world for the adaptation and coordination with the environment. From the perspective of Brenda and Robert Vale, the principles that should be followed to classify a building as an example of sustainable green architecture are [25]: 1) energy conservation, 2) climate work, 3) reduced use of new resources, 4) respect for users, 5) respect for site, 6) holism.

3.2 Green building

The construction industry undoubtedly has a profound impact on the environment, economy, health and productivity of residents. With the recent advances in the building industry, technology and knowledge are now provided to designers, builders, users and owners so that they could achieve the best economic and environmental benefits by building green buildings. The origin of green building is the process of building environmentally friendly buildings and conserving the energy. The value of green building can be examined in the cradle-to-grave cycle of a building. However, according to the international energy agency data, 40% of energy per building is consumed by buildings in the construction cycle until the operation [26].

The collection of the principles of green building design and construction is as follows: a) Site efficiency along with design by maximizing use of energy from water, electricity and other resources; b) protect health and safety of residents; c) reduce pollution and damaging environmental waste. We will discuss the design considerations, design philosophy, and air quality and point to the green building. The main sponsors and designers of green building construction include: Environmental Protection Agency (EPA), ISO 14040 and US Green Building Council (USGBC), where the USGBC designates the green building certification (LEED) as the most accredited expert group in this field [27].

3.3 Green concrete

Ordinary concrete has a great popularity in the construction industry with well-known advantages, but these wide applications are often associated with significant environmental impacts. So far, about 5 billion cubic meters of concrete have been produced worldwide, and this volume of concrete production requires the use of large volumes of natural resources for the production of aggregates and cement consumed in concrete [28].

Cement is one of the constituents of concrete and the production of one ton of cement releases one ton of carbon dioxide into the atmosphere. Carbon dioxide is known as a greenhouse gas and causes global warming. The destruction and disposal of concrete structures, on the other hand, results in the formation of large volumes of solid waste and water required to build concrete, where more than a trillion gallons of fresh water, albeit regardless of the water used for washing the aggregates and the water needed for the concrete curing, is annually used for the concrete construction. However, freshwater is not readily available in the world. The above issues show that the concrete industry has become an environmentally destructive industry, but studying the life cycle of this widely-used product in the construction industry can actually turn it into a kind of environmentally friendly material.

Consequently, to reduce the impact of Portland cement pollution on the environment, its use in concrete should be reduced as much as possible [29].

Green concrete is a concrete that uses recycled materials in at least one of its constituents, or that its manufacturing process does not lead to environmental degradation or that it has a high performance and durability in its life cycle. Many efforts have been made by researchers to make suggestions for significantly reducing the energy consumption and environmental impacts during the cement manufacturing process. The research covers a wide range of activities from applying the concepts of industrial environment to nanoparticles. In this case, nano-engineering studies the behavior of structure and organization of cement nanoparticles in the concrete mix to achieve higher performance. Even clean concrete production technologies, such as replacing a relatively high percentage of cement with fly ash (up to 100%), using natural pozzolans, developing the concrete recycling, using nanotechnology and achieving high-performance concrete in terms of tension, stiffness and durability have been studied and developed. Green concrete is an environmentally friendly concrete which satisfies all three areas of sustainable development: environmental, economic and social impacts. The factors that determine whether the concrete falls within the definition of green concrete are: amount of Portland cement replaced by other materials, manufacturing process and method, performance, and sustainable life cycle of concrete.

Green concrete should follow one or both techniques of the material recycling and the reduction of greenhouse gases. The three main concepts in the field of green concrete are: reduction of greenhouse gas emission (CO2 emissions from cement plants); reduced use of natural resources such as limestone, clay, river sand, natural rocks (regarded as non-renewable human resources); and use of recycled materials in concrete which results in air, land and water pollution. These concepts in green concrete will lead to the sustainable development and reduced degradation of natural resources and the environment [30].

3.4 Concrete pollution reduction strategies

The strategies for reducing the concrete pollution include: 1) Recycled materials, 2) Improved mechanical properties, 3) Cement additives, 4) Reuse wash water for aggregates.

One of the strategies for producing eco-friendly concrete is to reduce the use of Portland cement and to use pozzolans as an alternative. Pozzolans are silica or aluminum silica materials that are effective as a complement to ordinary Portland cement in enhancing the cohesion properties of concrete. These materials do not normally react with water, but can chemically react with lime or cement and increase the strength and durability of concrete. Pozzolans improve the properties of fresh and hardened concrete and are divided into two general categories of natural pozzolans and synthetic pozzolans.

Natural pozzolans mainly contain non-crystalline volcanic ash. They are extensively found in most parts of the world, including Iran. They have long been used with lime and then with Portland cement. Despite abundant resources, due to insufficient research on existing resources and their quality changes in the nature, their use has not significantly expanded and their consumption is estimated to be around 30 million ton [31]. Some of the most active Pozzolans in Iran include diatomite, pumice, and volcanic tuff [32]. The synthetic or industrial pozzolans mainly include silica fume, fly ash and rice husk ash.

3.5 Cement replacement

The reduction in Portland cement use can be achieved by replacing part of the cement by various materials such as fly ash, blast furnace slag granule, wood ash and limestone powder. The use of the materials also improves the properties of concrete, because it decreases the hydration heat of concrete and reduces the risk of shrinkage cracking and also increases the resistance of concrete to sulfate attack and reaction with alkali aggregates.

3.6 Fly ash

Application of the fly ash offers many advantages. Theoretically speaking, the Portland cement can be 100% replaced by the fly ash, though any replacement level beyond 80% requires the use of an active chemical. The fly ash can also improve certain properties of the concrete, including its strength. Generated as a by-product of coal combustion, the fly ash is widely available, making it important not only as it reduces the costs, but also as it contributes to the use of waste material and their restoration to the life cycle [28]. The fly ash is, indeed, the residual remained upon burning the coal powder, which is guided from the combustion chamber to the particle disposal system through a set of chimneys. All types of fly ash contain pozzolanic material which are originally free of any cement but rather chemically interact with calcium hydroxide in presence of hydration at conventional temperatures to form compounds with cementing effects. In this respect, the fly ash tends to improve the concrete efficiency. The filling effect, alkalinity, concrete reinforcement against the sulphates, improved concrete performance, reduced permeability, and reduced maximum temperature of the bulk concrete are some other advantages offered by the fly ash. Due to the spherical morphology of the fly ash particles, the fly ash naturally lowers the water content and hence improves the concrete performance [33].

The fly ash consumption for various applications has been estimated at 300 million tons. The largest producers of the fly ash include China, India, and United States, with a total global fly ash production of 850 million tons in 2010 and a forecasted production of some 1,000 million tons in 2020, of which 400 and 500 million tons are applicable in the cement and concrete industry, respectively. With the technological developments in the use of higher volumes of cement-replacing material, particularly the fly ash, for producing concrete mixes, especially for bulk concretes used in the dams, the replacement ratio has recently reached a historical record of 60%, highlighting the role of the fly ash in reducing the cement production and hence the carbonic gas emissions to the atmosphere. Generated as a by-product of coal combustion, the fly ash is widely available, making it important not only as it reduces the costs, but also as it contributes to the use of waste material and their restoration to the life cycle [32]. The coal ash is less expensive than the Portland cement though the coal ash-incorporated concrete offers high strength and long durability. Addition of the ash to the concrete precursors enhances the tensile strength of the concrete. A disadvantage of the coal ash as a replacement for the concrete is the low early strength of the resultant concrete. In this respect, one may use additives to accelerate the hydration to achieve high 28-day strength values. Reduced adhesion is another disadvantage that may occur due to incomplete combustion or non-uniform physical and chemical properties of the ash depending on the source coal, which can be addressed by performing further studies [34].

Fig. 1. Fly ash

3.7 Silpoz

Silpoze is, in fact, a super-pozzolan produced from the rice husk. Being composed of micron-sized particles, this product is very suitable for filling the gap between the cement and gravel particles in a concrete, so as to improve the strength and workability of the concrete while lowering the use of cement for concrete manufacturing. Based on experiments, it has been identified that the silpoz can increase the compressive strength of the concrete by 10 – 15% and further enhance the concrete resistance to chemicals, abrasion, and corrosion. In addition, this product lowers the hydration temperature of the concrete by 30%, thereby inhibiting the concrete corrosion and water intrusion by up to 60% [35].

3.8 Rice husk ash

Upon the rice milling operation, some 78% of the original rice weight is extracted as the rice grains while the remaining 22% is composed of the rice bran (husks) that is usually used to fuel the rice flour machine. The husk is composed of volatile organic matter at 75%, with the remaining 25% turning into the rice husk ash upon burning the original husks. The ash contains silica at 85 – 90%. When mixed with the fly ash and granule furnace slag, the rice husk ash offers a good additive to replace the Portland cement for concrete manufacturing, contributing to reduced CO_2 emission. Some 1% of the earth surface is covered by rice farms, providing a primary source of nutrition for billions of people around the world. Each year, some 600 million tons of rice is produced in the world, of which some 20% (i.e. 120 million tons) is composed of the rice husk [28].

Fig. 2. Rice husk ash

3.9 Micro-silica

The micro-silica is a special form of silicon dioxide, a highly desirable powdered product of the silicon alloying process. It is composed of spherical particles of 150 nm in average diameter. This glass-like fine-grained powder is produced through condensation of the silicon oxide gas, with its particles being smaller than those of conventional Portland cement by some 100 folds. The micro-silica is usually used at 7 – 12% of the cement by mass. The most significant application of the micro-silica is that it can act as a highly reactive pozzolan – i.e. a mineral additive. On a global scale, this product is being produced at some 2 million tons per year. It is generally regarded for special applications such as the structures exposed to aggressive chemicals, etc. However, the main application of this additive is to enhance the concrete strength by reducing its permeability as its micro particles tend to fill in the gaps in the cement mixture and hence produce a high-strength and durable concrete [28].

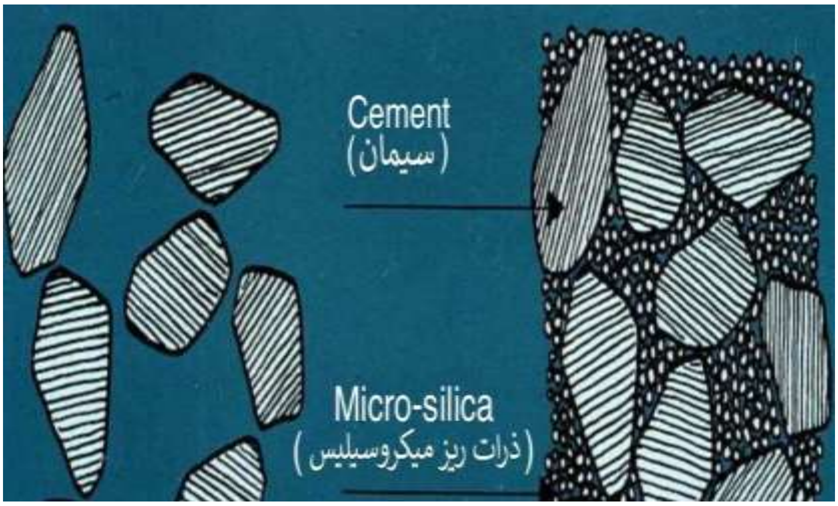

Fig. 3. Micro-silica

3.10 Silica fume

The silica fume is a by-product obtained upon reducing the highly pure quartz with coal or coke and firewood in an electric arc furnace for producing the silicon phase or ferro-silicate alloy. Th United States Environmental Protection Agency has acknowledged the silica fume as a valuable recyclable material for concrete structures. In general, the silica fume tends to lower the concrete permeability while increasing the concrete's water demand. It also ends up producing a more adhesive concrete mix. Accordingly, in order to achieve a lower water-to-cement ratio, one may need to use water-reducing additives to a silica fume-incorporated concrete mix [33]. Stats indicate that the annual production of the silica fume in the world has recently reached some 1 million tons. Given the significant quality of the silica fume and its application in other industries, rather than the concrete industry alone, almost all of the produced silica fume is consumed. Considering the low production of the silica fume compared to other artificial pozzolans (e.g. fly ash), the contribution of this material to reduced emission of carbonic gas is not significant, but the fact that it makes durable concretes implies its remarkable role in the sustainable development [33].

3.11 Calcined clay (metakaolin)

Obtained in small amounts from the calcination of the kaolin, the metakaolin offers appropriate pozzolanic effects, making it a candidate replacement for cement in the concrete. Given that some carbonic gas is emitted upon clay calcination, this material is not effective for reducing such pollution, but rather durable concretes produced upon incorporating this pozzolan place an emphasis on its role in the concrete durability and sustainable development.

3.12 Building lime

The building lime has long been used as a replacement for cement or directly incorporated into concert mix. As of present, mixtures of cement and the building lime have become standard materials for construction purposes. Easy incorporation of this material into the cement or concrete, its abundance in the nature, and reduced CO2 emission by lowering the cement production can promote the use of the building lime in the future. Currently, in many countries around the world, a minimum of 10% of the cement consumption has been replaced by the building lime. The European Standards introduced four types of limy cement wherein up to 35% of the cement was replaced with the building lime. It has been predicted that the use of the building lime at higher rates can reduce the CO2 emission through the cement manufacturing industry by 5 – 8% on a global scale. Many experts in the construction industry have considered the concrete as a living organism that requires constant maintenance during the useful life of the structure. This maintenance is particularly important in the early life of the concrete and plays a pivotal role in its long-term functionality. Today, respecting the significance of the harmony between the concrete industry and the environment, not only the expected concrete strength matters, but also the sustainability and durability of the concrete are equally important. Increased sustainability of the concrete provides a persistent and efficient solution for optimization of the construction industry. Naturally, as a concrete structure gets older, the concrete productivity and environmental impacts of the concrete itself as well as the constituent materials decline proportionally. As of present, a handful of codes and regulations have been developed for rebar coating, reduced water-to-cement ratio, minimum cement consumption and the type of used cement, crack width and trapped air constraints, etc. in an attempt to enhance the structures in terms of lifetime, depending on the structure performance. However, such standard codes require a clear definition of the useful life and desirable performance throughout time [32].

3.13 Geopolymer concrete

The geopolymer is a new construction material that is formed through chemical reactions on the inorganic molecules. The fly ash is a byproduct of the coal furnace that is produced in large volumes in thermal power plants. Being rich in silicon and alumina, it reacts with the aluminosilicate gel, as an alkaline solution, to form a strong adhesive for keeping the concrete components together. As an excellent replacement, this material provides for making concrete mixes with no use of the Portland cement. Compared to the conventional Portland cement, the geopolymer cement has opened a much greener window toward the concrete industry. The geopolymer concrete can also be manufactured using the metakaolin. Davidvits, the French scholar, was the first to introduce this geopolymer adhesive. According to the computations presented by this scholar in 2002, production of a geopolymer adhesive led to the emission of only 0.18 tons of CO2 per ton of the adhesive, while the corresponding figure to the Portland cement was higher by some 100 folds [2]. In this respect, this product is likely to rise an evolution in the environment-friendly concretes. The geopolymer concrete offers such advantages as fire resistance for up to 1000°C without emitting any toxic gas, improved resistance to acidic and salt-based solutions, cost efficiency and less greenhouse effect. Albeit, not all of inorganic polymers offer the entire set of these advantages, and the list may differ depending on source of the raw material, concrete formulation, and the mixing method, calling for further research works. It is worth noting that the concrete produced with such a polymer offers good adhesion properties against the ceramics, glass, metal surfaces, and old concretes [32].

Fig. 4. Geopolymer concrete

3.14 pplication of recycled material

The construction industry is the largest consumer of the raw material. In this respect, some 40% of the natural resources exploited on the earth is spent on construction projects. In the meantime, Iran produces and consumes more than 33 million tons of cement per year, exploits more than 220 million tons of sand and gravel from domestic resources each year, and consumes more than 60 million liters of water, on an annual basis, for preparing concrete mixes, washing different materials and machineries, and cure the concrete. All of these highlight the important role of the correcting, controlling, and guiding different processes in the concrete industry to reduce the cement consumption and air pollution while pushing the country forward to the sustainable development [33].

3.15 Slags

The slag is an artificial product produced during iron production at iron blast furnace. Upon cooling, it can be used in many applications including the slag cement production. Being lighter than the iron melt and hence accumulated on top of the iron melt, the slag melt must be removed from the furnace to produce granular material. Presently, the iron furnace slag is being produced in bulk and granular forms at an annual rate of 125 million tons on a global scale, of which 90 million tons are consumed. With further development of iron foundry plants, larger masses of the slag will be produced in the world. Knowing the cement-like properties of this material, which makes it a good replacement for the cement (at up to 90 wt.%), it has been projected that large volumes of the produced slag will be used in concrete works around the world [36].

Fig. 5. Slags

3.16 Csting sand

Also known as metal casting sand, the casting sand is a silica-rich sand with excellent physical properties. As a byproduct of metal casting process, this product has long been used as a molding material in the casting industry. In the modern casting operation, this sand is even recycled. According to stats, some 100 million tons of slag is consumed in the construction industry each year, of which some 4 – 7 million tons are disposed that could otherwise be used in other industries.

Fig. 6. Casting sand

3.17 Waste glass

The waste glass is another example of the suitable materials for using as aggregates in the concrete. The use of such recycled glasses tends to reduce the landfilling so that the LEED standard has acknowledged that as a concession. The glass is a unique material that can be recycled for multiple cycles without changing its chemical properties [37].

3.18 Damaged concrete

Damaged concrete is a suitable replacement for the aggregates in novel concrete mixes. Since the largest fraction of the concrete is composed of the aggregates, the reuse of the damaged concrete lowers the disposal of the construction waste largely and rather turns the material back to the construction cycle and hence contributes to the protection of the natural environment.

4. PRESENTATION OF RESULTS

About 8 to 10% of the total CO2 emission in the world is made by the cement production. The green concrete refers to a concrete product into which some waste material has been incorporated and its production process imposes no harm to the environment while providing for adequate strength and sustainability. Much effort has been done to significantly attenuate the impacts of the energy-intensive cement production process on the environment, leading to the emergence of such concepts as the industrial environment, the green chemistry, and the nano-engineering where the behavior of the nano-structured material are studied to enhance the cement performance. Clean technologies for concrete production include the mass replacement of cement with ash, incorporation of natural pozzolans, application of recycled waste material for concrete manufacturing, and utilization of nanotechnology and nanoparticles. Rational and knowledge-based application of the environment-friendly materials, recycled materials, and construction wastes in the concrete preparation, as a fundamental element of the construction industry, where such materials may serve as either filler or adhesive, has been a crucial objective followed by the concrete technology. As long as the engineering science is used as a tool to realize this objective, i.e. application of the biocompatible and environment-friendly construction materials, it can contribute to the sustainable development, architecture, and structure; the use of the green concrete is not an exception to this general rule.

We hope that this research can serve as a step toward the environmental protection in the scope of the construction industry.

4.1 Recommendations

It is recommended to introduce a dedicated part on the green concrete in the Iranian Concrete Code and the Iranian National Building Code in an attempt to promote the use of this type of concrete in the Iranian construction industry, as is the case in the developed countries. It is also recommended to formulate governmental incentives for the use of the green concrete offered to contractors and stakeholders of the civil projects, so as to reduce the need for cement in the construction industry. An obligation to utilize the green concrete in government-funded projects can also lower the environmental emissions generated by the cement factories. The Iranian scientific and academic communities are also expected to undertake more applied researches and laboratory works on the strength and mechanical properties of the green concrete to extend the scope of application of the green concrete in the civil projects performed in Iran.

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