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Review Research

A REVIEW OF THE EFFECT OF ADDITIVES ON THE MECHANICAL PROPERTIES OF LIGHTWEIGHT CONCRETE

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Abstract: Many organizations around the world have recognized lightweight, long-lasting, cost and environmentally-friendly construction materials as a future necessity. The lightweight concrete is manufactured mainly either by replacing the original aggregate with lightweight aggregate or addition foam production materials to concrete mixtures. These additions lead to a decrease in the lightweight concrete density and change mechanical properties such as compressive strength. Therefore, there is much experimental research has been conducted to add different material types that can improve lightweight concrete compressive strength while maintaining low density. In this review, the effect of various additions such as steel fiber, product waste materials, and nano-materials on the lightweight concrete compressive strength and density have been explained. The various effects of these additive materials on lightweight concrete properties, some additives lead to improving the properties of lightweight concrete, while other materials lead to a decrease in those properties, and this depends on the type and amount of material additive, the method lightweight concrete manufacturing, and their mixture composition.

Keywords: *Compressive strength; fiber materials; waste materials; palm oil clinker; nano-materials*

1. Introduction

Concrete is the first construction material around the world, and the most widely used material in all forms of civil engineering construction project types, concrete output is expanding every year [1-3]. The total amount of concrete used globally by weight is twice aluminum, steel, wood, and plastics put together. As a result, the concrete industry has grown into a massive commercial business and it is not easy to overstate the effect of this material on our life today [4]. Despite the most important concrete advantages, there are two big drawbacks, which are having low tensile strength and high density [5].

Lightweight Concrete (LWC) is a versatile material to reduces the high-density disadvantage of concrete that has a great interest and great industrial demand in later years in different types of construction projects, despite its acknowledged use dating back over 2000 years [6, 7]. Lightweight concrete is defined as concrete having a density (air-dry) below 2000 kg/m^3 as compared to normal concrete with a density in the region of 2350 kg/m^3 [8, 9]. Lightweight concrete (LWC) is the building material used in the construction of buildings using the most recent technology to diminish the self-weight of the building. Lightweight concrete can be manufactured by various methods; such as using a lightweight coarse

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aggregate, using parts of lightweight fine aggregates instead of normal aggregates such as (Pumice stone) or volcanic stone, adding an aerated concrete agent as an admixture of aluminum powder to the normal concrete mixture with or without coarse aggregate or by using foam produce materials [4]. In recent years, the lightweight concrete used for construction projects has very quickly grown because using LWC would reduce the total costs of the buildings by reducing the volume of the foundation, the steel reinforcement, and vertical member's cross-sections that keep the used horizontal area [7]. In fact, the future need for building materials, that are lightweight, durable, economical, and environmentally sustainable has been identified by many groups around the world. Therefore ,some additives have been added to lightweight concrete to enhance its mechanical properties, leading to improving its durability .

Various additive materials are used to enhance the lightweight concrete's properties. So, in this review, the additives materials to LWC are categorized into three groups: fibers, waste product materials, and nanomaterials, and explained their effect on LWC properties.

2. Materials Additions

2.1. Fiber Materials

Fiber-reinforced concrete's (FRC) behavior depends on the quality of the binding matrix and the interaction of the fibers placed in the concrete which are the most important factors in FRC. As a result, different sorts of fibers are added to the concrete, causing it to behave differently.

The length, geometry, diameter, proportion, and fiber kind, as well as the type of material, influence the FRC's performance. As a result, choosing the type of fiber in FRC requires careful consideration.

The major goal of incorporating fibers into the concrete is to enhance properties such as compressive, toughness, tensile, flexural, and impact resistance, as well as to control the formation of cracks. Steel fiber reinforced concrete is more resistant to cracking, has a higher impact, and flexural strength. Concrete with steel fibers has been the subject of a lot of research in the past [10-12].

Fiber from natural resources is the most cost-effective and more environmentally friendly than other fiber types that are utilized in concrete with minimal environmental impact. This allows concrete's mechanical properties to be improved. Researchers discovered that it is possible to increase the quality of FRC using different natural fibers, including coconut fiber. The coconut fibers taken out from the shell of the coconut can withstand up to 6% more strain than regular concrete without reinforcing fibers. Lad et al. [13] studied the effect of husk ash and coconut fiber on concrete mechanical properties; the presence of such materials together in the concrete mixture increases workability and compressive strength. Due to their strong affinity for water and retention nature, the inclusion of coconut fibers reduces the workability of concrete. Lumingkewas et al. [14] studied that the addition of steel fibers to lightweight concrete could diminish the brittleness of LWC. Singh and Choi et al. [15, 16] demonstrated that steel, polyethylene, and vinylon fibers affect LWC properties. The individual adding 1.5% vinylon fiber and 1.2% steel fiber increased the flexural strength and the fracture toughness, respectively, for all prepared lightweight concrete samples. Dvorkin et al. [17] reported that adding steel fiber to the content of 11.5% by volume could increase the compressive strength of concrete by 102.5%. The experimental study was done by Libre et al. [18] showed that adding 0.4% of polypropylene fiber (PP) to pumice lightweight concrete can decrease its density and compressive strength from 1760 kg / m3 to 1740 kg/m3 and from 18.7 MPa to 17.1 MPa, respectively. While adding 0.4% PP. and 1% SF increase the density to 1880 kg/m3. Adding 0.5% SF can increase compressive strength from 18.7 MPa to 30.2 MPa for the LWC made with natural pumice. Al-Naimi and Abbas [19] showed that one volume percentage of steel fibers has little influence on the lightweight aggregate concrete and limestone aggregate concrete's compressive strength. Wang and Wang [20] made their experiments show that steel fiber addition has a slight influence on compressive strength. However, it can increase the bending, splitting tensile, impact strength, and improve toughness. Grabois et al. [21] showed that steel fibers had no important effect on the compressive strength of LWC. Wang et al. [22] showed that, with increasing exposure temperature leads to a decrease in both the compressive strength and modulus of elasticity of steel fiber-reinforced lightweight concrete. Aghaee et al. [23] demonstrated that the compressive strength can increased by adding up to 0.5% by volume of the fiber either waste steel wires or industrial steel fiber to the structural lightweight concrete and can support in preventing concrete brittle failure. Zinkaah [24] showed that the lightweight concrete with added 0.75% by volume of steel fiber, and coarse aggregate product of brick crushing increased the concrete's compressive strength by around (17-43) % and (21-51) % at 7 and 28 curing days, respectively. While increasing the added steel fiber percentage from 0.75 to 1 vol. percentage, led to a reduction of compressive approximately (40%) compared with an added 0.75% of steel fiber at 7 and 28 curing days, respectively. The addition of steel fiber can increase flexural strength, splitting tensile strength, absorption, and elasticity modulus. Kaur and Singh [25] mentioned that lightweight concrete reinforced with waste steel fiber has comparable effects to normal fiber-reinforced concrete and better mechanical behavior can be obtained with added steel fiber to LWC than fiber made of any other material. Hassani Niaki et al. [26] showed that the incorporation of 10, 2% of silica fume and steel fiber, respectively, with the lightweight concrete made by lightweight fine aggregate (LWFA) from lightweight expanded cay aggregate (LECA) could improve concrete compressive strength to about 68 MPa at 28 days.

Wu et al. [27] showed that the use of steel and carbon fibers in lightweight concrete has increased tensile strength but little influence on compressive strength. Othuman Mydin [28] investigated the effect of the addition of polypropylene fibers on compressive strength for LWC by increasing the concrete porosity. This effect for polypropylene appears for Lightweight Foamed Concrete (LFC) has low density. However, these do not affect the strength of compressive for LFC high density. Haryanto et al. [29] demonstrated that the volume fraction of the fiber ranged between 0.3, 0.6, and 0.9%. To facilitate the casting process, the superplasticizer is added 2% by weight of cement, which lead to the production of lightweight concrete with a density below 2000 kg/m3 and improves the split tensile strength. The highest increase in split strength (61%) was obtained with an added 0.3% fiber.

2.2. Waste Production Materials

There are great ranges of industrial byproducts, waste materials and vegetal byproducts that can be used as aggregates in the concrete mix. The materials that can be used to replace the cement and aggregates in usual lightweight concrete are waste aggregates the same as those that can be used in normal weight concrete, with the exception that the density must be less than 2000 kg/m3.

Venkatesh and Vamsi Krishna [30] studied the using of the pumice 25 and 33.3 volume percentage to replace the aggregate, and fly ash's (15%, 20%, 25%, and 30%) were used to replace cement in the lightweight concrete mixture. The maximum compressive strength, split tensile strength, flexural tensile strength, and Youngs modulus of 26.3%, 19.23%, 26% and 3.33%, respectively observed with incorporation of 20% fly ash and 33.33% Pumice aggregate. Hosen et al. [31] demonstrated that the reducing in tensile strain, brittleness, and strength of high-strength lightweight concrete (HSLWC) when they used the Palm Oil Clinker (POC) as coarse aggregate, were overcome by adding hooked end steel fibers. Density stays from 1940 kg/m3 to 2060 kg/m3 when the steel fibre content is 0 to 1.50% by volume, respectively. The compressive strength increases from 51.5 MPa for POC to about 61 MPa after adding 1.5% of hooked end steel fibers. Setyowati [32] used industrial waste of Styrofoam and fly ash as replacing aggregate and cement in concrete, respectively, to produce LWC, which offers excellent seepage resistance and compressive strength. The concrete mix with the addition of 15% fly ash results in a better compressive strength.

Singh [33] used 10 to 15% percentage of waste marble powder that replaced cement in M20, M30, M40 grades of concrete, increased the workability, compressive strength, flexural, and split tensile strengths of concrete. Aslam et al. [34, 35] used solid wastes that are produced by the palm oil industry are oil palm boiler clinker (OPBC) and oil palm shell (OPS). Coarse aggregate made from OPS is lightweight. Therefore, concrete utilizing OPS as a coarse aggregate in the mix results in a weak concrete. As a result, in an OPS lightweight concrete, OPBC was employed to replace 40- 50 percent of the OPS. The results revealed that when OPS was replaced by OPBC, splitting tensile, compressive, flexural, splitting tensile strengths improved significantly. Passos et al. [36] studied the using of red ceramic block waste (40 percent and 100 percent) by volume, as lightweight aggregate used to replace natural coarse basalt aggregate in concrete mixtures. As a result, concrete fire resistance is improved, i.e., losses in concrete compressive strength and elastic modulus are reduced.

Selvaprasanth et al. [37] reported that the concrete density was reduced by 50% while adding pumice stone. Waste recycling powder of polypropylene is low specific density with fly ash used to close concrete voids to enhance their properties by filling these voids. That led to compressive strength improved from 8.6 MPa to 13.6 MPa. Jusi et al. [38] showed that the compressive strength of lightweight brick is improved by using silica fume as replace 5%, 10%, and 15% of the cement weight percentage in lightweight brick mixture. The best replacement percentage of silica fume is 5%, leading to an increase in the compressive strength by 41%, 57%, and 41% for 7, 14, and 27 curing days, respectively when compared with normal lightweight brick. Pichór et al. [39], showed that the mortar conductivity coefficient and the compressive strength of mortar matrix decrease as the amount of granulated foam glass GFG increases, although it can be improved by substituting sand for part of the lightweight materials as filler or adding ground expanded perlite to the matrix. Carvalho and Motta [40] used four different concrete mixtures with added expanded polystyrene were prepared. The results showed that the lightweight concrete compressive strength and density of the concrete were decreased by adding expanded polystyrene (EPS) and recycled expanded polystyrene as aggregate in the concrete mixture when compared with the reference concrete mixture. Dawood et al. [41] investigated the use of polyethylene terephthalate (PET) as aggregate in concrete, which has shown different effects on density, compressive and flexural strength. The 5% PET of the aggregate is the correct percentage to obtain higher concrete compressive strength than other replacing percentage. Increasing the PET dosage by up to 15% reduces flexural strength and density.

Jasmin and Hafiz [42] showed that applying scrap tires reduces the environmental effect and maximizes the preservation of natural resources. Atef et al. [43] demonstrated that it is possible to use recycled, non-biodegradable tire rubber as a replacement for some of the cement. Chosh and Bera [44] demonstrated the ability of producing lightweight concrete using used rubber tire aggregates. Fadhli [45] studied the tire rubber as aggregate replacement in 10%, 15%, 20% and 25% of the overall volume of concrete coarse aggregate. The compressive strength of concrete decreases with an increase in tire aggregate percentage was added. This is because of the lack of good bonding between rubber aggregate and the concrete mix. Asutkar et al. and Fioriti et al. [46, 47] showed that the density of concrete produced from rubber and metakaolin aggregates is less than 2000 kg/m3, and the decreasing in concrete strength depends on the percentage of rubber. Fawzy et al. [48] introduced four concrete blends with replacement rates of 4%, 8%, 12%, and 16% sand by rubberized crumbs from waste tires. Similar samples were exposed to 70°C for 4 hours to investigate the impact of elevated daily temperatures, and a 2-hour period for temperatures of 200°C and 400°C in order to investigate the effect of the fire. The compressive strength of the concrete was reduced in case of temperature rise. Muyen et al. [49] showed that the lower density and strength of rubberized concrete can be used on lightweight walls. Mehrani et al. [50] added 5% rubber powder can enhance the tensile and compression strength of concrete foam. Alves Oliveira et al. [51] demonstrated that tire rubber is used as fine aggregate to replace some of the natural aggregate in lightweight clay concrete. That causes reduced density and strength, but increases water absorption compared to lightweight expanded clay concrete without rubber aggregate.

Záleská et al. [52] investigated the physical and mechanical properties of using tire rubber as fine and coarse aggregate in concrete mix were tested at different temperatures. The results showed a decreasing in unit weight, strength, and the thermal conductivity of concrete.

2.3. Nano Materials

Nano-materials have excellent physical-mechanical properties. The following types of nano-materials nano-silica (NS), and carbon nanotubes (CNTs) were actively explored and employed for building purposes. The use of carbon nanotubes improves the properties of construction composites, while reducing the need for pricey components, making these materials more used in the building materials industry. The nanoscale reinforcement particles have the filler quality, allowing for the development of materials with higher density than that material without nano reinforce. In addition, it allows for the slowing and prevention of crack growth during the initial stages of concrete hardening, as well as an improvement in the overall quality of the matrix aggregate at the phase boundary. Zhang et al. [53] investigated the influence of Nano silica NS on properties of lightweight concrete. The flexural and compressive strength of concrete is increased when the Nano silica percentage increases. Vaganov et al. [54] studied how to achieve high performance concrete, and to investigate if utilizing other admixtures, such as carbon nanotubes (CNT), and possibility to localize alkali silica reactions to improve the durability of foam concrete. Sldozian et al. [55] found that when (0.0004-0.0012 percent) CNTs (Taunit 24) and NS are combined in modest dosages are added to lightweight concrete with granulated foamed glass, compressive and flexural strength is increased by (up to 68 percent) and (up to 34 percent), respectively, as well as decrease water absorption by (8%). Afzali Naniz and Mazloom [56] found that the combined of using of silica fume and colloidal nano silica (CS) significantly improved the self-compacting lightweight concrete characteristics than when used only CS. Elrahma et al. [57] tested the NS-containing lightweight concrete. The findings revealed that NS altered the fine pore structure, and improved the concrete's transport properties. Hashemi and Mirzaei Moghdam [58] used the lightweight concrete produced by using lightweight expanded clay aggregate (LECA) as coarse aggregate and silica fume to replace part of cement in the concrete mix, then added the polypropylene fibers (0.5% and 1%) and nano-silica NS (1.5% and 3%) weight percentage of cement in the LWC. The effect of polypropylene fibers and nano-silica on bonded and compressive strength was investigated. Polypropylene fibers reduced the density and strength of LWC samples, but added 1.5% of NS can recuperate and increase bonding and compressive strengths of LWC samples, especially when curing for 28 days. The optimal ratio for achieving maximum tie strength between reinforcement and (LECA) aggregate in lightweight concrete is 1.5 weight percent replaces cement with nano-silica NS and 1% vol. of polypropylene fibers is added to concrete. Ghanbari et al. [59] produced lightweight self-compacting concrete containing scoria and a mixture of zeolite, glass fiber, and NS particles. These combined, in addition, increased the splitting tensile strength and electrical resistivity. Ismail et al. [60] demonstrated that the addition of nano-silica to light expanded clay aggregate (LECA) improves durability, compressive strength, and splitting tensile strength for LWC depending on the nano-silica percentage and age of concrete. The optimum amount of nano-silica to obtain maximum compressive strength is 0.75% at ages 7, 28 and 90 days.

3. Conclusions

Three groups of additive materials types and their effect on the properties of lightweight concrete LWC are explained.

Fiber materials, added steel fibers to the WC could diminish the brittleness and increase the compressive strength.

The polypropylene fibers have no effect on increasing the strength of high density LFC, while it has an effect on compressive strength value for low density LFC.

Use up to 0.3% of soda can waste fibers to reinforce LWC led to increased split tensile strength, which can help to close and stop the cracks, and prevent the flaws growth matrix.

Waste Materials; improved compressive strength for LWC observed with incorporation of fly ash and LWA Pumice aggregate. While using the waste recycled powder of polypropylene with fly ash, fly ash can fill a void that causes to enhance the concrete's characteristics.

The addition of steel fiber to oil palm clinker concrete OPC used to replace part of normal aggregate will improve the concrete's compressive strength.

It has also shown that individual use of PET and EPS polymer waste as aggregate in a mixture of lightweight concrete reduces their density and compressive strength.

Nano materials; Nano silica NS, colloidal nano silica CS and carbon nanotubes CNT is used to improve characterization of the LWC. The effect of nano materials depends on the type of aggregate, such as used micro silica and CS is more effective on LWC than only used (CS). The polypropylene fibers and nano silica NS decreases density, but increases compressive strength.

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Conflict of interest

The authors confirm that there is no potential for interest conflict in the publishing of this paper.

Author Contribution Statement

Author Raed K. Mohammed proposed the search for the problem, developed the methodology, and performed the overview, and assessment of the proposed indicators.
Author Mohammed J. Kadhim participates in collecting, analyzing references, and writing manuscripts.
Author Hamza M. Kamal participated in discussing the results.
All authors contributed to the manuscript.

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