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FULL LENGTH ARTICLE

Mechanical properties of self-compacted fiber concrete mixes

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Abstract Increased productivity and improved working environment have had high priority in the development of concrete construction over the last decade. The major impact of the introduction of self-compacting concrete (SCC) is connected to the production process. The productivity is drastically improved through the elimination of vibration compaction and process reorganization. The working environment is significantly enhanced through avoidance of vibration induced damages, reduced noise and improved safety. Additionally, SCC technology has improved the performance in terms of hardened concrete properties like surface quality, strength and durability. The main objective of this research was to determine the optimum content of fibers (steel and polypropylene fibers) used in SCC. The effect of different fibers on the fresh and hardened properties was studied. An experimental investigation on the mechanical properties, including compressive strength, flexural strength and impact strength of fiber reinforced self-compacting concrete was performed. The results of the investigation showed that: the optimum dosage of steel and polypropylene fiber was 0.75% and 1.0% of the cement content, respectively. The impact performance was also improved due to the use of fibers. The control mix specimen failed suddenly in flexure and impact, the counterpart specimens contain fibers failed in a ductile manner, and failure was accompanied by several cracks.

Introduction

The concept of self-compacting concrete (SCC) was proposed in 1986 by Hajime Okamura [1], but the prototype was first developed in Japan in 1988 by Ozawa [2]. This new concrete was deliberately designed to be able to fill every corner of the form and encapsulate all reinforcements only under the influence of gravitational forces, without segregation or bleeding. These advantages make SCC, particularly useful wherever placing is difficult as in heavily reinforced concrete members or

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in complicated work forms. Through extensive research, it has been established that the addition of fibers to concrete considerably improves its structural properties such as compressive strength, static flexural strength, impact strength, tensile strength, ductility and toughness [3–10]. Felekoğlu et al. [11] reported that using SCC with its improving production techniques is increasing every day in concrete production. Domone [12] carried out an analysis for 68 case studies addressing the applications of SCC. He calculated the mix proportions of SCC. 31.2% by volume of the mix were a coarse aggregate. The paste content was 34.8% by volume. The powder content was 500 kg/m^3; water/powder ratio was 0.34 by weight, and the fine aggregate/mortar was 47.5% by volume. Uysal and Yilma [13] studied the effect of using different types of mineral admixtures on the fresh and hardened properties of self-compacting concrete. They mentioned that the use of marble powder was the most suitable with regard to the properties of fresh SCC. On the other hand, Khaleel et al. [14] reported that the coarse aggregate properties had a direct effect on achieving SCC. Maximum size, texture and type of coarse aggregate were the factor effects on the flowabilty of concrete. They found that the flow-ability of SCC decreases with the increase in the maximum size of coarse aggregate and using crushed aggregate with the same water to powder ratio and superplasticizer dosage. However, mix design methods and testing procedures are still developing. Zhu and Bartos [15] studied that permeation properties, which include permeability, absorption, diffusivity, etc., have been widely used to quantify durability characteristics of SCC. The results indicated that SCC mixes had significantly lower permeability than the vibrated normal reference concretes of the same strength grades. Furthermore, SCC mixes containing no additional powder but using a viscosity agent were found to have considerably higher diffusivity than reference mixes, and other SCC mixes. However, it is necessary assuring that this enhancement on the mechanical properties is not accompanied by a detrimental effect on the durability properties. Conventional fiber reinforced concrete is a special type of concrete that has been strengthened by adding fibers to the wet concrete mix. Concrete is quite brittle and while high levels of compressive strength can be achieved; the tensile strength is relatively low, which makes it likely to crack under many conditions. Fiber reinforced concrete is less probable to crack than conventional concrete. In the early years of the 20th century, asbestos fibers were added to concrete. In 1960s, a variety of fibers, including polypropylene, glass, and steel fibers were used in concrete [16]. Fiber reinforced concrete is commonly used in pavements and floors. It can also be used in foundations, pillars, precast forms, and beams in combination with traditional steel reinforcements. Fibers are usually used in concrete to resist cracking due to plastic and drying shrinkage. Numerous researchers have studied the effects of fibers on plastic shrinkage cracking behavior as reported in ACI 544.5R-10. A general observation is that thin fibers are more impressive in reducing the width of plastic shrinkage cracks than thick fibers as reported in ACI 544.5R-10 [17]. Most thin-diameter micro fibers with a high specific fiber surface area are particularly effective in reducing plastic shrinkage cracking [18]. Moreover, the use of fibers helps in reducing the permeability of concrete and its tendency to bleed [14]. A number of studies have been conducted to investigate the relationship between fiber reinforced concrete (FRC) and water permeability [18,19]. Some types of fibers produce greater impact, abrasion and shatter resistance of concrete. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) and termed the volume fraction (Vf) [19]. The effect of fibers on the mechanical properties of concrete such as compressive strength, splitting tensile strength and flexural strength was reported by Alonso, 2008, Sena-Cruz, 2004 [20] and many other researchers. Some studies on the impact resistance of fiber reinforced concrete showed that self-compacted reinforced composites under impact were capable of dissipating much higher energy compared with conventional fiber reinforced concrete with polymeric or steel fiber [21]. Bindiganavile and Banthia, 2002 observed that the measured impact response was highly dependent on the characteristics of the dropping weight of the impact machine used for testing. Results appear to be far less sensitive to the mass of the hammer than to the drop height [21–23]. When self-compacting concrete becomes so widely used that it is seen as the "standard concrete" rather than a "special concrete" it will be possible to have durable and reliable concrete structures that require very little maintenance work. The development of SCC was an important step toward efficiency at building sites, rationally producing prefabricated concrete elements, better working conditions and improved quality and appearance of concrete structures. By adding fibers to SCC it is possible to enhance the performance of concrete structures. Fiber self-compacting concrete combines the benefits of SCC in the fresh state and an enhanced performance of fiber reinforced concrete in the hardened state.

Experimental program

To achieve the aim of the research, a two-stage program was conducted. In the first stage, different mixes were prepared to specify the best mix which achieves the requirements of Technical Specification for SCC. In the second stage, six mixes were prepared to determine the optimum content of fibers used in the fresh state of SCC, which are based on the finding of the first stage. A total of 90 cubes $10 \times 10 \times 10$-cm were tested to determine the compressive strength of the mixes at 7 and 28 days. Cylinders of 10 cm in diameter and 20 cm in length were studied to determine the splitting tensile strength of the mixes. To determine the flexural strength of mixes and impact strength; $10 \times 10 \times 50$-cm prisms were used.

Materials

Well graded siliceous sand was used with a specific gravity of 2.60, absorption of 0.78%, and a fineness modulus of 2.61. A coarse aggregate of crushed dolomite with maximum nominal sizes of 10 mm and 14 mm was used, with a specific gravity of 2.64 and absorption of 0.76%. Locally produced Portland cement (CEMI: 42.5 N) conforming to the requirements of Egyptian Standard Specifications (2005/373) was used. Imported class (F) fly ash meeting the requirements of ASTM C618 [24] with a specific gravity of 2.1 was used. Fly ash was added by 10% of the cement content. The cement content was 400 kg/m^3 and the water powder ratio (W/P) ranged from (0.35 to 0.4). Tap water was used for mixing the concrete. A high range water reducer (HRWR) with a trade name; Addicrete BVF was used as superplasticizer meeting the requirements of ASTM C494 (types A and F) [25]. The admixture