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Combined Effect of Glass Fiber and Polypropylene Fiber on Mechanical Properties of Self-Compacting Concrete

Совместное действие стеклянной и полипропиленовой фибры на механические свойства самоуплотняющихся бетонов

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Abstract. Self-compacting concrete is a state-of-the-art technology actively used all over the world in the construction field. This concrete, which has high performance, can be used for casting heavily reinforced sections, in places where vibrators have restricted access for compaction and when complex shapes of formwork are used. Otherwise it may be impossible to cast and the obtained surface is superior to the one achieved with the use of conventional concrete. On the other hand, using various types of fibers can enhance mechanical and dynamical characteristics of concrete as well as reduce cracking in concrete. In this study, we research both combined and individual effects of polypropylene and glass fiber on mechanical and rheological properties of self-compacting concrete. In order to do so, 10 specimens have been made including those containing (A) polypropylene fiber with volume fraction of 0.1, 0.2, 0.3 and glass fiber with volume fraction of 0.1, 0.2, 0.3 and (B) combined polypropylene and glass fiber. The results of these experiments have shown that combined polypropylene and glass fiber can enhance tensile and bending strengths. In addition, these additives dramatically increases toughness of concrete.

Аннотация. Самоуплотняющийся бетон – строительная технология, активно применяемая во всем мире. Этот бетон с высокими эксплуатационными характеристиками может быть применен в конструкциях со значительным содержанием арматуры в сечениях, в местах, труднодоступных для вибрационных уплотнителей и при использовании опалубки сложных форм. С другой стороны, укладка такого бетона требует особых условий. Использование разных типов фибры может повысить механические и динамические характеристики бетона, а также улучшить трещиностойкость. В данном исследовании изучается как совместное, так и собственное влияние полипропиленовой и стеклянной фибры на механические свойства и реологические характеристики самоуплотняющегося бетона. Для этого были изготовлены 10 образцов, в том числе с долей полипропиленовой фибры 0.1, 0.2, 0.3, с долей стеклянной фибры 0.1, 0.2, 0.3 и с совместным использованием полипропиленовой и стеклянной фибры. Результаты экспериментов показали, что совместное действие полипропиленовой и стеклянной фибры повышает прочность на растяжение и изгиб. Кроме того, эти добавки значительно повышают прочность бетона.

Introduction

Self-consolidating concrete was introduced to improve quality of concrete in 1811, and the first study on the performance of self-consolidating concrete was carried out by Ozawa (1818) and Okamura (1883) in Tokyo University [1-3]. According to one theory, self-consolidating concrete or self-compacting concrete (SCC) is characterized by a low yield stress, high deformability, and moderate viscosity necessary to ensure uniform suspension of solid particles during transportation, placement (without external compaction), and setting [4]. There are several advantages in utilizing this material; building faster and reducing human labor due to the use of self-compacting concrete (SCC), optimizing durability owing to reducing permeability, simplifying the design. However, it has some disadvantages and one of them is low tensile strength, due to low plasticity and high brittleness. To compensate this flaw, bars are used as reinforcement in concrete. Still, using bars is not always practical and may entail bigger costs; for instance in water canals shelling, furnishing, airports and so on. In this case, fibers have been used for several decades in concrete, which spreads evenly.

Destruction and deterioration of concrete depends on cracking and micro-cracking caused by loads or environmental impacts. Thermal and moisture changes in cement paste cause micro-cracking. With increasing loads and other related environmental impacts, micro-cracking spreads in concrete body [5].

Utilizing divergent fibers in concrete and producing fiber-reinforced concrete (FRC) is an effective way to preclude cracking and micro-cracking from spreading and ameliorate tensile strength of concrete. The prominent properties of concrete are absorbing energy, flexibility, resistance against impact. Due to this fact, this concrete plays a pivotal role in developing technology and is known as unprecedented and economical material [6].

Resistant glass fibers in concrete have been studied by Marsh and Clarc for the limited condition of testing after (14) days and curing in air at 50 percent, and 23 °C. Fiber with a length between 12mm and 50mm was used in a volume between (0.5) percent and (2.5) percent. Various mix proportions were examined using (10) mm maximum sized river gravel aggregate, water reducing admixtures and about (5) percent of entrained air. The use of fiber has gone through quite big development in the last 30 years. Fiber Reinforced Concrete (FRC) constitutes one of the most relevant innovations in the field of special concrete [7, 8]. The effect of incorporation of polypropylene fiber on the mechanical properties of polypropylene fiber self-compacting concrete has been determined as flexural toughness and remarkable ductility [9]. Some research has been conducted regarding the properties of fiber self-compacting concrete in recent years. However, most of the studies are limited to research distinctively polypropylene and glass fiber. In this study, both of them are used proportionally. This study is aimed at investigating systemically the mechanical properties of polypropylene and glass combination in self-compacting concrete.

Materials

Cement

We used Portland cement type 2, which properties are shown in Table (1) below.

Table1: chemical properties of cement

Chemical composition	Percentage	Chemical composition	Percentage
SiO ₂	21.25	CaO	64.07
Al ₂ O ₃	4.95	MgO	1.20
Fe ₂ O ₃	3.19	SO ₃	2.04
K ₂ O	0.63	Na ₂ O	0.38

Superplasticizer

For the study we used GLENIUM_110P, which is a high performance concrete superplasticizer [10] based on modified polycarboxylic ether. GLENIUM 110 P is differentiated from conventional superplasticizers as it is based on a unique carboxylic ether polymer with long lateral chains, which greatly improves cement dispersion. At the start of the mixing process, the same electrostatic dispersion occurs as described previously, but the presence of lateral chains, linked to the polymer backbone, generates a steric hindrance, which stabilizes the cement particles capacity for separating and dispersing. This mechanism provides flowable concrete with greatly reduced water demand.

Fibers

We used polypropylene and glass fibers having the following properties mentioned in Table (2).

Table2: physical and mechanical properties of fibers

Aspect ratio	Diameter (mm)	Length (mm)	Tensile strength kg/cm ²	Young's modulus kg/cm ² *10 ⁵	Specific gravity gr/cm ³	shape	fiber
120	0.1	12	4500	0.5	0.91	smooth	polypropylene
600	0.02	12	14000	7.2	2.5	smooth	glass

Aggregates

Maximum size of gravel was 12.5 mm, which has a grading diagram in the domain of ASTM standards [11]. In addition, sand was sieved with mesh no 4.75 and we used rock flour with 2.6 g/cm³ of specific gravity and density 2.5 as a filler. Fillers such as rock powder can fill a void in concrete, which leads to decreased porosity of concrete [12].

Mix design

We followed the instruction of ACI 237R-07 mix design to attain self-consolidating concrete [13].

Considering prior reports, we expected that the more we used fibers the less performance of self-compact concrete would be [14]. [ACI 544.4R] Therefore, in mix design for self-compacting concrete, we attempted that the concrete without fiber has high performance regarding [ACI 237R-07] so that after adding fibers it would have good quality in performance analysis.

10 specimens of mix design which include A and B, (A) polypropylene fiber with a volume fraction of 0.1, 0.2, 0.3 and glass fiber with a volume fraction of 0.1, 0.2, 0.3 and (B) combined polypropylene fiber and glass fiber. Moreover, for all these mix designs, we considered all the components as constant apart from the type and amount of fiber. Table (3). Water cement ratio (W/C) is 0.39, and we determined number 1 design without fiber as a control plan. VF in the table is the fiber volume fraction, which is the ratio of fiber volume to concrete volume. Different amounts of polypropylene fiber based on manual and retaining performance specified 0.9, 1.4, 1.8 kg/m³, and glass fibers 3.75, 5, 7.5 kg/m³.

Table 3. Concrete mix design

Mix NO.	Series	Fiber vf (%)	Gravel	Sand	Lime stone powder	Cement	Water	SP	
1	A	*	722	826	288.7	413.2	163	7.7	
2		P.P	0.1	722	826	288.7	413.2	163	7.7
3			0.2	722	826	288.7	413.2	163	7.7
4			0.3	722	826	288.7	413.2	163	7.7
5		Glass	0.1	722	826	288.7	413.2	163	7.7
6			0.2	722	826	288.7	413.2	163	7.7
7			0.3	722	826	288.7	413.2	163	7.7
8	B	0.1P.P+0.2 Glass	722	826	288.7	413.2	163	7.7	
9		0.15P.P+0.15 Glass	722	826	288.7	413.2	163	7.7	
10		0.2P.P+0.1 Glass	722	826	288.7	413.2	163	7.7	

Curing and preservation

After completing our mix, the specimens were kept in a mold in the laboratory conditions for 24 hours and then they were kept in a water pool at 22-25 °C. Each mix design had 9 cubicle specimens of (10*10*10) cm, 6 cylinders of (30*15) cm, 3 beams of (50*10*10) cm and 1 cylinder of (20*10) cm [15].

Rheology of fresh SCC

In this study, we used a mix design, which, in spite of using fibers in concrete, has a property of self-compacting concrete. To analyze the performance of self-compacting fiber concrete, we applied the standard parameters for self-compacting concrete [16]. We used an L-BOX experiment for analyzing stability of SCC against detachment and we applied a slump test for analyzing deformation of concrete flow [17]. The slump test for self-compacting concrete was similar to that for ordinary concrete but has one difference. After concrete pervaded on the table, we had to measure intersection of two perpendicular diameters and the average of this measurement indicated concrete flow [18].

In addition, the time (in seconds) to reach 500 mm had to be recorded regarding demarcation on the slump test screen which implied the rate of deformation with definition of distance flow. With the L-BOX test, we could measure the height of fresh SCC after embedding it along the steel rebar and flowing in certain direction so that we could estimate the power of passing and blockage which had to be at least 0.8. The results of the measured physical properties of fresh SCC is shown in Figures (1), (2) and (3). According to the European standards, slump must be in the range of 60-75 and time T50 must be at least 3 seconds and 6 seconds at the most.

Hardened concrete

Compression strength and Young's modulus

Tensile strength was tested based on (B.S 1881: Part 116) standard. Curing conditions and experiment parameters were the same in the experiments. The results are shown in Table (4) and Figures (4) and (6). We used cylinder specimens (32*15) in order to analyze Young's modulus (ASTMC 469).

Tensile strength

Tensile strength of the concrete was determined by indirect test methods: (1) a split cylinder test and (2) a flexure test. For this study, we wanted to have more consistent results so we applied a split cylinder test in accordance with ASTM-C469, the results of which are shown in (5a) (5b) (5c).

Bending strength and bending endurance tests

In this experiment, our objective was to determine the modulus of rupture and bending endurance according to ASTM C78 and ASTM C1018-94b, which was implemented on a specimen (52*12*12) at a universal device, which had a strain control mechanism with velocity of 0.5 mm/min. The distance between two supporters was 40 cm [20].

Universal device

Table 4. Results of compression strength of 28 days concrete

Mix NO.	Series	Fiber vf (%)	Compressive Strength (MPa)	
1	A	*	74.4	
2		P.P	0.1	72.5
3			0.2	70.7
4			0.3	65.8
5		Glass	0.1	73.8
6			0.2	72.3
7			0.3	69.6
8	B	0.1P.P+0.2 Glass	73	
9		0.15P.P+0.15 Glass	72.5	
10		0.2P.P+0.1 Glass	70.4	

Conclusion

Pursuant to the results of workability of self-compact concrete, we consider that using fibers has a negative effect on rheology properties of fresh SCC. It reduces workability and increases both consistency and viscosity.

Considering the fact that fibers inherently have acceptance performance against tensile and bending, our results demonstrated that the more fibers we use the bigger resistance to bending and tension is and the more brittle it can be before rupturing.

In this experimental study, concretes contain different fibers and have different mechanical properties. As for concretes, which include polypropylene fiber, increase of the fiber percentage up to 0.3%, resulted in a fall of the compression strength. This downward trend is also common for concrete containing glass fibers.

Our experiments demonstrated that the effect of combined polypropylene and glass fibers lead to decrease in compression strength, however, with substitution of 0.3% by volume of fibers in combination especially in (0.1P.P+0.2 Glass), we see the maintenance of compression strength.

Our experiments demonstrated that in concretes containing polypropylene and glass fibers, the more fibers are added the higher the resistance of tensile and bending strengths we get.

In the existing mix, if we increase fibers to add in self-compacting concrete, we will see exceeding resistance of tensile and bending strength.

From our results we can assert that polypropylene and glass fibers had slight changes and caused to diminish Young's modulus. The effect of combined polypropylene and glass fiber lead to decrease in Young's modulus.

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