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Optimal Amount of Flag and Fly Ash in Steel Fiber Reinforced Concrete

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Abstract

This experiment research adopts ordinary portland cement with the strength grade of 42.5, mixed it with slag, fly ash and water reducing agent to prepare C40 steel fiber reinforced concrete (SFRC). Via observing the compressive strength changes of steel fiber reinforced concrete when different amount of steel fiber, slag and fly ash were mixed, reasonable amount of steel fiber was determined with the maximum compressive strength of concrete. As a result, as concentrations of minerals and sand ratio changed, the compressive strength of concrete varied regularly. In addition, when the strength was maximum, the amount of steel fiber proved to be constant with the value of 1.4%.

Key words: Slag; Fly ash; Water reducing agent; Compressive strength; Reasonable amount of steel fiber

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INTRODUCTION

Ordinary concrete is prepared by mixture of sand, stone, cement, water, etc. and widely used in modern architecture. It has the characteristics of available materials, easy production, high compressive strength, easy pouring for buildings of earthquake-resistance and overall high requirements. Nevertheless, ordinary plain concrete has low tensile strength and adaptability, is a breakable material and easily becomes crisp under the loads such as earthquake. In addition, this concrete easily breaks with cracks for one reason or another during construction. Hence the current steel fiber reinforced concrete may make up for the various drawbacks of ordinary concrete, as steel fiber is added to ordinary concrete so as to increase its compressive strength and resistance against tension, bending and in particular tenacity after its break (Lin & Yang, 2012). Compared with ordinary concrete, concrete with high-performance and lightweight aggregate has the advantages of light weight, high strength and good durability and are to be widely applied in construction engineering (Gong & Liu, 2006). However, researches indicated that the tension and compression ratio of this concrete was smaller than ordinary concrete with the same strength grade, and as strength increased, its crispy accordingly increased, which prevented the material with high strength from exploiting its advantages and limited its application in engineering (Zhang, 2012). Steel fiber composite is simply one of these materials. Researches on steel fiber concrete are closely associated with those on other composites. Therefore additives of slag and fly ash for concrete may not only protect the environments, save the cost of concrete mixed with much cement, but also increase its compressive strength, improve its performance and more or less play the role of water reducing agent (Wang, 2009). On the other hand, cementing material with slag is of high density, high strength and low energy-consumption. In times of rapid development of industry and concrete technology, concrete with various admixtures appear to be environment-protecting and economical. Its fine products may partly replace pottery, metal, polymer and also ordinary portland on many occasions of high requirements. Slag is smooth in its surface, has fine particles and many spherical glasses. Hence it may fill in ettringite and cement so as to increase the density of the obturator. Apart from that, addition of slag to cementing material may increase the flowability of the slurry.

1. EXPERIMENT

1.1 Materials

Granulated blast furnace slag: Produced by Wuhan Iron & Steel Plant and finely ground by laboratory with its specific surface area 4320 cm^2/g;

Fly ash: Class A fly ash; producer: Xiangfan Tianjian Co., Ltd; named Jiahong;

Ordinary portland cement: Named Yangfang; strength grade 42.5;

Stone: Particle size 5~20 mm, well graded gravely;

Sand: Well graded medium-coarse sand;

Steel fiber: Steel fiber named Hansen; manufacturing location: Wuhan, Hubei Province, China;

High-effect water reducer: NFJ-1 high-effect water reducing agent; manufacturing location: Wuhan, Hubei Province, China.

1.2 Specifications and Requirements for Concrete Sample Preparation

For the sake of application in engineering, this experiment intended to prepare concrete with the most frequently used strength grade C40 in engineering. According to the specifications and requirements, 100×100×100mm was adopted for the solid square concrete sample. During the experiment, the slump of concrete admixture was controlled between 10~30mm and maintained in standard laboratory. The chosen test ages were respectively 7d, 14d, 28d and 60d. Among the samples were ordinary concrete mixed with steel fiber and steel fiber reinforced concrete. Contrastive analysis of test data was made to determine the concrete with maximum compressive strength when the amount of steel fiber was optimal.

1.3 Experiment Calculation and Data Measurement

During the experiment, volume ratio was used for steel fiber and mass ratio for other materials. C/W remained the same with 0.41; steel fiber and water reducing agent were additives. The blending ratio of other materials were determined according to the purposes to be achieved. For sand ratio, it was 41%~48% and for steel fiber it was 0.8%~2.0%. Slag and fly ash were equal amount of substituting cement. Mix proportion of ordinary cement was calculated for the various materials needed, among which steel fiber and water reducing agent were admixtures, slag and fly ash were additives of equal amount of replacing cement. As for the ratios and measured data, see Table 1~4.

Table 1
Mix Proportion and Measured Compressive Strength for No.1~16 C40 Steel Fiber Reinforced Concrete

No.	Sand ratio (%)	Mix proportion (%)		Waterreducing agent (%)	Amount of steel fiber (%)	Measured compressive strength (Mpa)			
		Cement (%)	Slag & fly ash			7 d	14 d	28 d	60 d
1	41	100	0		0.8	46.20	47.40	54.60	57.60
2	43				0.8	48.50	49.60	56.11	59.22
3	45				0.8	49.50	51.40	56.20	59.80
4	47				0.8	48.51	50.61	55.20	59.10
5	41				1.0	44.61	45.81	48.51	54.61
6	43				1.0	47.31	49.80	53.61	57.31
7	45				1.0	50.00	52.62	57.20	60.51
8	47				1.0	47.50	52.31	54.80	57.61
9	42				1.2	45.61	48.81	54.20	58.41
10	44				1.2	49.61	51.52	55.61	60.42
11	46				1.2	50.81	52.91	57.82	61.44
12	48				1.2	46.42	49.42	54.72	59.62
13	48				1.4	51.42	53.84	58.26	61.91
14	48				1.6	49.61	51.81	56.82	59.93
15	48				1.8	48.51	50.22	54.92	58.23
16	48				2.0	45.72	47.93	52.63	55.83

Table 2
Mix Proportion and Measured Compressive Strength for No.17~25 C40 Steel Fiber & Water Reducing Agent Reinforced Concrete

No.	Sand ratio (%)	Mix Proportion (%)		Waterreducing agent (%)	Amount of steel fiber (%)	Measured compressive strength (Mpa)			
		Cement	Slag & fly ash			7 d	14 d	28 d	60 d
17	42	100	0	0.6	0.2	45.20	47.10	51.20	54.12
18	44	100			0.4	47.52	48.93	54.31	57.31
19	44	100			0.6	49.91	52.11	56.82	59.21
20	45	100			0.8	51.21	53.02	57.61	61.32
21	46	100			1.2	52.61	55.62	59.62	62.62
22	48	100			1.4	53.54	56.52	60.61	66.11
23	48	100			1.6	51.31	53.62	58.43	61.54
24	48	100			1.8	50.13	51.62	56.41	59.83
25	48	100			2.0	47.36	49.87	54.22	57.42

Table 3
Mix Proportion and Measured Compressive Strength for No.26~35 C40 Steel Fiber, Fly Ash & Water Reducing Agent Reinforced Concrete

No.	Sand ratio (%)	Mix Proportion (%)			Waterreducing agent (%)	Amount of steel fiber (%)	Measured compressive strength (Mpa)			
		Cement	Fly ash	Slag			7d	14d	28d	60d
26	42	85	15	0	0.6	0.2	44.62	46.51	50.42	53.65
27	44	85				0.4	46.71	48.22	53.83	56.95
28	44	85				0.6	49.31	51.42	55.93	58.86
29	45	85				0.8	50.63	52.34	57.64	60.75
30	45	85				1.0	50.82	55.86	57.94	64.33
31	46	85				1.2	53.67	57.21	58.62	65.42
32	48	85				1.4	54.12	58.93	59.64	66.51
33	48	85				1.6	50.73	52.94	57.85	60.96
34	48	85				1.8	49.53	51.84	56.56	59.67
35	48	85				2.0	46.72	49.34	54.35	56.96

Table 4
Mix Proportion and Measured Compressive Strength for C40 (No. 36~45) Steel Fiber, Minerals & Water Reducing Agent Reinforced Concrete

No.	Sand ratio (%)	Mix Proportion (%)			Waterreducing agent (%)	Amount of steel fiber (%)	Measured compressive strength (Mpa)			
		Cement	Fly ash	Slag			7 d	14 d	28 d	60 d
36	42	75	10	15	0 · 6	0.2	45.03	47.64	51.15	56.91
37	44					0.4	46.62	49.63	54.34	58.93
38	44					0.6	49.31	52.62	56.55	60.76
39	45					0.8	50.62	53.13	58.06	62.06
40	45					1.0	51.64	54.65	59.66	62.56
41	46					1.2	52.43	55.54	60.46	64.37
42	48					1.4	52.62	56.93	60.86	65.27
43	48					1.6	50.72	53.63	58.84	62.05
44	48					1.8	49.64	52.85	56.96	61.27
45	48					2.0	46.85	49.97	54.88	58.56

1.4 Result

From Table 1 (No. 1~16) it could be seen that without admixtures of slag, fly ash and water reducing agent, the compressive strength for No. 1-13 concrete increased as sand ratio and amount of steel fiber changed and gradually decreased after that (No. 14~16). The maximum strength grade was No. 13 when the maximum measured compressive strengths for 7d, 14d, 28d and 60d were respectively 51.42Mpa, 53.84Mpa, 58.26Mpa and 61.91Mpa with the amount of steel fiber 1.4%.

From Table 2 (No. 17~25) it could be seen that without admixtures of slag and fly ash, and when 0.6% water reducing agent was added, the compressive strength for No. 17-22 concrete increased as sand ratio and amount of steel fiber changed and gradually decreased after that (No. 23~25). The maximum strength grade was No. 22 when the maximum measured compressive strengths for 7d, 14d, 28d and 60d were respectively 53.54Mpa, 56.52Mpa, 60.61Mpa and 66.11Mpa with the amount of steel fiber 1.4%.

From Table 3 (No. 26~35) it could be seen that when 15% fly ash and 0.6% water reducing agent were added, the compressive strength for No. 26-32 concrete increased as sand ratio and amount of steel fiber changed and gradually decreased after that (No. 33~35). The maximum strength grade was No. 32 when the maximum measured compressive strengths for 7d, 14d, 28d and 60d were respectively 54.12Mpa, 58.93Mpa, 59.64Mpa and 66.51Mpa with the amount of steel fiber 1.4%.

From Table 4 (No. 36~45) it could be seen that when 10% fly ash, 15% slag and 0.6% water reducing agent were added, the compressive strength for No. 36-42 concrete increased as sand ratio and amount of steel fiber changed and gradually decreased after that (No. 43~45). The maximum strength grade was No. 42 when the maximum measured compressive strengths for 7d, 14d, 28d and 60d were respectively 52.62Mpa, 56.93Mpa, 60.66Mpa and 65.27Mpa with the amount of steel fiber 1.4%.

2. ANALYSIS

Table 1 indicated that without water reducing agent and minerals, the optimal amount of steel fiber was 1.4% and table 2 revealed that with water reducing agent the optimal amount of steel fiber remained the same. From table 3 and 4 it could be seen that with water reducing agent and fly ash or with both of them and slag, the optimal amount of steel fiber was still 1.4%. Hence it could be concluded that in the steel fiber reinforced concrete, steel fiber is the key factor that affects the compressive strength much more than other ones.

As minerals exert less influence on the compressive strength of concrete than steel fiber, minerals can be added to the concrete to be the equivalent substitution of cement so as to save the amount of cement, make full use of renewable resources, decrease the cost and protect the environments. The hydrate in slag densifies the boundary surface between fly ash and cement base and increases slag's micro material effect, which reveals their compensation in terms of particle properties (Sun, 2009). Apart from that, according to the composite mechanical theory and fiber distance theory, although each component of the materials has strong compressive strength, the macro or overall compressive strength is weak so long as concrete breaks, due to the fragility of concrete and the existence of weak link on the boundary surface of cement and fine aggregate and also mortar and coarse aggregate. The addition of steel fiber may leap over both sides of the fracture so that the bond stress between the concrete on both sides of steel fiber and fracture limits the extension of fractures. At the same time mineral admixture has become a must of modern concrete and addition of minerals may increase the complexibility of concrete system. Therefore composite aggregates such as steel fiber, fly ash and slag cement are needed since concrete composed of various materials has obviously composite effect. SFRC (steel fiber reinforced concrete) is such a kind of composite material which possesses fine physical and mechanical properties. In addition, as mechanism of the steel fiber in SFRC plays a key role, the optimal amount of steel fiber will not be changed when fly ash, slag and water reducing agent are added.

3. FEATURES AND REINFORCED MECHANISM OF SFRC

3.1 Features

In 1910 Porter proposed the concept of steel fiber reinforced concrete (SFRC). SFRC is a composite construction material with steel fiber added into ordinary concrete. Steel fiber is distributed evenly and in all directions, prevents the extension of breaks in the concrete base, increases concrete's intensity of tension, shear strength, torsion, crack and wear resistance, exceedingly improves its fracture toughness, impact resistance and highlights its durability.

3.2 Reinforced Mechanism

Based on the fact that steel fiber limited the extension of fracture in the concrete, Romuldi (1963) proposed the fiber spacing theory. Within the concrete there are micro-cracks and small openings of different sizes. Affected by external factors, there will be high stress concentration in the openings, which may cause the extension of cracks and leads to the destruction of concrete. Addition of steel fiber to the fragile base may effectively improve the composite material's ability to prevent the occurrence and extension of cracks before and after it is pressed so as to reinforce the strength and toughness of steel fiber and concrete. The main role of steel fiber in concrete is to limit the extension of cracks in the concrete base. At the initial stage of loading effect, each component of the composite material bears the external force. After the break of the base, however, the steel fiber in and between the cracks becomes the main bearer. If sufficient steel fiber is added, the whole structure of SFRC can bear certain amount of load and great deformation until steel fiber is broken or pulled out of the base. For steel Fiber's mechanical reinforced mechanism on concrete, see Figure 1. Figure 1 (a) reveals the stress concentration of the internal cross section when the concrete base is pulled by the external force P and cracks occur. Figure 1(b) indicates the stress distribution of internal cross section when steel fiber is added in all directions. The steel fiber which leaps over the fracture will pass on the load, the crack area can still bear the load and the stress concentration on the end of the crack is decreased and further extension of the crack is effectively limited.

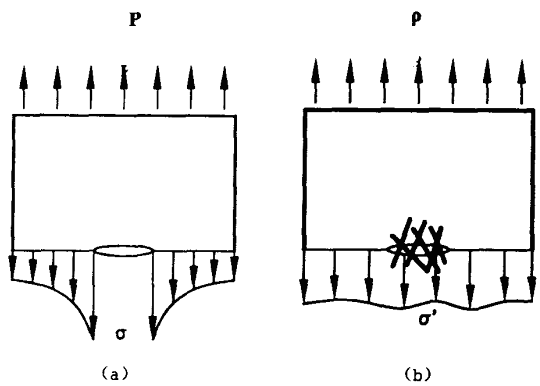

Figure 1
Reinforced Mechanism of Steel Fiber
Note. (a) stree concentration; (b) stree distribution.

4. APPLICATION

Steel fiber reinforced concrete has been used more and more widely, in particular bulk mass concrete. As such concrete is thick in volume, cement in hydration produces large amount of heat which causes the high temperature in the concrete and also the temperature difference within and without. In addition, the low tensile strength and small elastic modulus of concrete lead to the fracture and affect the construction quality. The overlong, ultra thick and cast-in-place reinforced concrete structure in industrial and civil architecture or reinforced concrete works such as continuous foundation, box foundation, equipment foundation and radiation shield wall need crack control. With the development of concrete technology, industrial by-products such as blast furnace slag and fly ash, etc. have been more and more used in the production of dense and waterproof concrete.

4.1 Application of Steel Fiber in Reinforced Concrete Structure

In the important locations that need earthquake-proof and other complex stress zones that bear power load, steel fiber reinforced concrete may improve the force tolerance and easily meet the requirements of bending resistance and local compression one. In the frame architecture, frame nodes play the role of passing on, distributing internal forces and ensure the structural integrity. In the core areas of nodes, force tolerance is complex and the stiffness of the nodes mainly depends on the strength of the concrete in the area. Application of steel fiber reinforced concrete in the nodes of beam columns can obtain greater shear strength and fine stretchability, increase their stiffness and anti-cracking performance more or less, and avoid the steel congestion in the nodal regions, convenient for construction. Compared with ordinary concrete framework, the stretchability of steel fiber reinforced concrete structure is increased about 57%, energy consumption capacity 130% and the number of load cycles 15% so as to strengthen the integrity or wholeness of the structure and its seismic fortification performance (Du, 2004).

4.2 Application of SFRC in the Transfer Girders of Tall Buildings

In tall buildings, there are often transfer girders that have different functions so that they need intermediate structures and transfer of different structures through structural transfer floor. Transfer girder is an important component of the structure and on most occasions an eccentric tension member, bears great shear force and has high requirements of anti-shear and crack because it bears complex stress and high load. Huafu Building in Fuzhou, China, adopted steel fiber reinforced concrete in full volume in all the transfer gilders of the top of the eight floor and the amount of steel fiber was 1% of concrete in volume. Due to the steel fiber reinforced concrete, the shear capacity of gilders was significantly increased and was 45% higher than that of the concrete with the same grade, which was more economical and reasonable than thick plate transition and saved a layer of architectural space (Ying, 2008).

4.3 Application of SFRC in Roof Waterproof and Building Floor

Traditional rigid waterproof roof easily breaks and cracks. SFRC has high anti-cracking performance and when used for waterproof roof it may integrate covering layer with waterproof layer and need no reinforcing bars with fine waterproof function and moderate cost, suitable for roof and parking apron greening. In 2003, the first-stage project of the 1st line track traffic, Wuhan, China, adopted SFRC for its roof panel of the platform layer, Qiaokou Road parking lot. Compared with other ordinary concrete panels with the same grade and construction conditions, this project used SFRC grade CF30 which had significant effect on anti-cracking and waterproof. SFRC can also be used for the floors that are affected by wear, seriously impacted by heavy load with high requirements of anti-cracking, shock resistance and wearability. In addition, it is also suitable for the floors with no joints within a large range, large-area ground loading or floors which have other special requirements. For example, a paper company with pulp board warehouse floor used forklift truck for transport and piling up of goods. On this occasion the floor is required to be smooth and hard-wearing, does not sink or crack with no obvious bending or deformation. The adoption of SFRC does meet these requirements and prove to be economical and reasonable (Sun, 2009).

4.4 Application of SFRC in the Columns and Shear Walls of Tall Buildings

As for the columns and shear walls of tall buildings, SFRC with high strength is mainly used for the bottom floor so as to increase its bearing capacity, and decrease the section size of column and shear wall components. Nevertheless, SFRC with high strength is of great breakability and when its strength is over 100Mpa it becomes exceedingly fragile and abruptly cracks under axial compression. And the addition of steel fiber may improve the performance of SFRC (Wei, 2005).

4.5 Application of SFRC in Ordinary Wall Engineering

SFRC can be used in ordinary wall engineering. As load bearer of the wall, SFRC may constitute a composite wall structure according to the use function of the wall. At present there are two types of construction: wet and dry. The former uses expansive cement composed of SFRC as mortar material, forms overburden on the surface of the benzene board which is used as the heat shield of the wall by means of spray or trowelling so as to form composite wall made up of concrete and benzene board. The latter uses SFRC to prefabricate thin wallboard as overburden of the heat shield and precut metal fasteners to connect it with the wall itself (Yi, 2005). Construction speed proves to be fast when SFRC is used for precast panel as wall, which is favorable for construction industrialization. In addition, in building construction, jetting concrete technology can be adopted in the slope protection of underground structure, basement concrete wall, renovation and reinforcement of old houses, etc.. Precast piles made up of SFRC can also be used for pile foundation. To sum up, reasonable use of SFRC technology may be of great help to solve the technical problems for stress positions in complex engineering (Wang, Zhao, & Wang, 2006).

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