Study on fundamental properties of the spraying Ultra High Strength Fiber Reinforced Concrete cured at normal temperature

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Abstract. In this study, the hardened properties and spraying characteristics of ultra high strength fiber-reinforced mortar mixed with copper fibers along with nylon fibers and polypropylene fibers are examined. The chemical fibers are added in the expectation that they will prevent cracking during initial curing. It is confirmed that, even with the addition of chemical fibers, the fresh properties of the mortar are similar to those of formulations containing only copper fibers. It is also found spray-application of this formulation achieves sufficient application thickness and that on-site application would be possible.

1. INTRODUCTION

In Japan, much of the concrete infrastructure built in the 1960s is deteriorating and is in need of seismic reinforcement, especially given that major earthquakes are anticipated in the near future. Sprayed concrete is an attractive reinforcement option that can also find application in the construction of marine structures, where it can improve workability. The advantages of the spraying method include the absence of formwork, rapid working, the ability to work in any direction including upward and workability under adverse conditions, such as on a slope. In recent years, there have been an increasing number of reports about repair and reinforcement using concrete spraying, such as repairing the cross section of concrete structures, augmenting floor slab thickness form the underside, and seismic reinforcement work.

When implementing sprayed concrete for seismic reinforcement, the requirements are good spraying performance, high hardened strength, and good durability. In order to meet these requirements simultaneously, thixotropic properties are imparted to ultra high strength fiber-reinforced mortar, and mixed with fine powders such as silica fume, copper fibers, and chemical fibers such as nylon fibers, and polypropylene fibers.

2. Study on curing properties of sprayed UFC

In this study, researchers examine the hardening properties of UFC obtained by adding copper and chemical fibers to mortars in the low water-cement ratio region and containing silica fume and similar fine powders.

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2.1 Materials

The materials used in this work are shown in Table 2-1. The copper fibers are used to investigate improvements in bending strength, while the nylon and polypropylene fibers are expected to prevent cracking in the initial stage after spraying.

Table 2-1 Materials used

Material	Symbol	Density (g/cm³)
Ordinary portland cement	OPC	3.16
Silica fume	SF	2.25
Blast furnace slag 20000	BS20	2.91
Anhydrous gypsum	H-AG	2.90
Fly ash	H-FA	2.67
Wollastonitea	WO	2.91
Silica sand	S	2.61
Tap water	W	1.00
Superplasticizer	SP	0.60
Defoamer	DF	1.00
Retarder	RE	1.17
Copper（50μm×2.5mm）	Cu	8.90
Nylon（28μm×10mm）	N	1.14
Polypropylene（64.8μm×12mm）	PP	0.91

2.2 Mixes

The base case is an addition of 1.25% copper fibers and other mixes are obtained by adding a proportion of chemical fibers.

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Based on the compounding in a previous study1), W/P is reduced from 17% to 16% in this study for further strength enhancement.

In Tables 2 -2 and 2 -4, the mix proportions are expressed as a volume ratio.

Table 2-2 Mix

Water to powder ratio	Sand binder ratio	Fiber content	0-stroke flow value
(%)	(%)	(%)	（m m）
16	30	1.25	120±10
Air amount	Addition amount of SP	Addition amount of DF	Addition amount of RE
(%)	(%)	(%)	(%)
≦2.0	0.25	1.0	0.15

Table 2-3 Powder composition

OPC	SF	BS20	H-FA	H-AG	WA
54	10	20	5	5	6

Table 2-4 Fiber content

	Fiber content（%）		
Combination	Cu	N	PP
Cu	1.25		
Cu+N	1.25	0.025	
	1.25	0.05	
	1.25	0.1	
Cu+PP	1.25		0.025
	1.25		0.05
	1.25		0.1

2.3 Mixing method

Kneading was carried out using a Hobart mixer in batches of 5L. For kneading, the binder and fine aggregate were premixed in a bag, then added to the mixer and kneaded at low speed for 30 seconds. After scraping off the dough, the water, water reducing agent and defoaming agent were added and the mix kneaded at low speed for 1 minute. The mix was then scraped off and kneaded at medium speed for a further 3 minutes. All fibers were then added and the mix kneaded at medium speed in 2-minute increments for about 6 minutes until the mortar reached condition.

2.4 Test method

・Flow value test

Performed in accordance with ASTM C1437.

・Air content test

Performed in accordance with BS EN 1015-7.

・Compressive strength test

Performed in accordance with BS EN 1015-11 after curing in water for 7 and 28 days.

・Bending strength test

Performed in accordance with IS EN 998-2. Curing conditions were as for the compressive strength test.

2.5 Results of fresh and curing properties tests

The results of the fresh property tests for each formulation are given in Table 2-5, showing that the desired properties were obtained for each formulation. The addition of N fibers increased the 0-stroke flow value compared with the other formulations, but it was confirmed that the addition of chemical fibers did not result in significant change the 0-mortar flow value. Figures 2-1 and 2-2 show compressive strength and bending strength test results for each formulation after curing in water for 28 days, respectively.
The target compressive strength of 150 N/mm^2 was achieved with the mixture containing only Cu fibers. However, the target was not achieved with the addition of N and PP fibers. One of the reasons for this is thought to be that the viscosity of the already thixotropic mix increased due to interference between the Cu and chemical fibers, resulting in voids when the test piece was cast. In this study, where the assumption is that the mortar will be sprayed, it is necessary to examine rate of defoaming agent and water reducing agent addition.
The target bending strength of 20 N/mm^2 was achieved except in the case of one formulation. It is considered that the addition of chemical fibers does not affect the development of bending strength; the same bending strength as with Cu fibers is assured even when chemical fibers are added. Further, no pullout of chemical fibers was observed in the fracture cross section, and the fibers were well dispersed in the mortar so they did not interfere with the copper fibers.

Table2-5 Fresh property test result

Combination	0 stroke flow value（mm）	Air amount (%)	Temperature (℃)
Cu	117	0.99	22

Cu+N0.025 %	114	0.96	22
Cu+N0.05%	125	0.19	19
Cu+N0.1%	130	0.42	20
Cu+PP0.025 %	118	0.5	21
Cu+PP0.05 %	112	0.41	22
Cu+PP0.1%	112	0.73	22

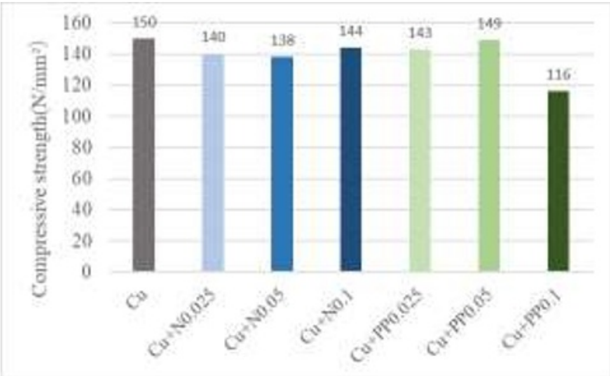

Fig. 2-1 Compressive strength after 28 days of curing in water

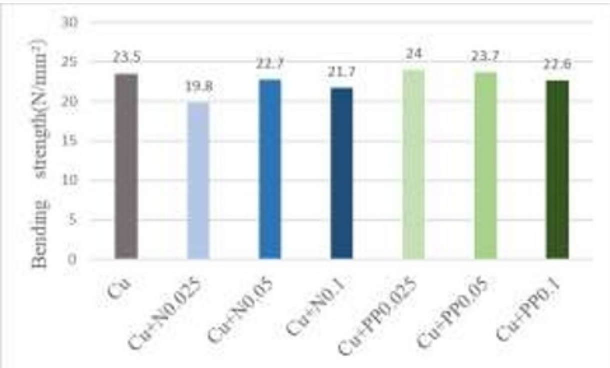

Fig. 2-2 Bending strength after 28 days of curing in water

Based on these results, the mixes with only Cu fiber, 0.1% N fiber and 0.05% PP fiber, which had a good expression of compressive strength and flexural strength, were selected for a further examination of spraying methods and initial crack testing. These are outlined below.

3. Spraying and the Durability of Sprayed UFC

Spraying tests were carried out with the three mixes selected for further testing: Cu fiber only, 0.1% N fiber, and 0.05% PP fiber. The initial cracking of the same mixes was also investigated.

3.1 Materials used and blending conditions

The materials used, powder composition, and fiber content were the same as in the previous chapter. A further formulation condition was also examined by adjusting the amount of SP added to 0.20% or 0.22% depending on the conditions.

3.2 Initial crack test method

Mortar was applied to a flat concrete panel with an area of 300 mm x 300 mm and a thickness of 10 mm. A primer was initially applied to the panel on the assumption that this would be the field methodology. The mortar was cured at constant temperature and humidity for a day and then any cracks were visually identified. The width and length of all identified cracks were measured using a crack scale. To evaluate these initial cracks, when multiple cracks were identified, the most representative ones were extracted and compared with the average crack length and width and the total area of the length and width.

3.3 Spraying and initial crack test results

The sprayed thickness obtained for each formulation is given in Table 3-1. Sufficient thickness was obtained with all formulations, a result that is considered due to the added thixotropic property, which increased fluidity during the pumping resulting in a vigorous spray, but ensured loss of fluidity as soon as the mortar hit the wall. No mortar slipped from the wall after spraying and all formulations are considered applicable to actual site work.

Table3-1 Spray thickness in each formulation

Combination	Temperature (℃)	0 mortar flow value（mm）	Sprayed thickness (mm)
Cu(SP0.20%)	22	102/100	
Cu(SP0.20%)	22	95/94	34
Cu+N0.1%(SP0.25%)	20	149/145	26
Cu+N0.1%(SP0.20%)	20	101/100	19
Cu+PP0.05%(SP0.22%)			34
Cu+PP0.05%(SP0.20%)	20	95/97	Trowel coating

The results of the initial crack identification are shown in Table 3-2. All formulations subjected to this test had an SP addition of 0.20%. Multiple cracks were identified in all formulations tested for initial cracking.

Images of the initial crack test panel for each formulation are shown in Photos 3-1, 3-2, and 3-3. The PP fiber formulation was the best of the formulations studied because the cracks are the widest but are short. It can also be said that the PP fiber has the effect of suppressing initial cracks in the area of a crack. In a previous study2), it was reported that mortar with added PP fibers had the ability to suppress plastic shrinkage cracking. In this study, however, the addition of chemical fibers had no observable effect on initial cracking. In the future, it will be necessary to implement this kind of initial crack testing using combinations of an increased number of additives as well as using a protective coating after mortar spraying.

Table3-2 Initial crack test results

Combination	Width (mm)	Length (mm)	Area (mm^2)
Cu	0.11	58.58	6.67
Cu+N0.1%	0.10	53.67	6.00
Cu+PP0.05 %	0.11	46.92	5.57

Photo3-1 Initial crack test results for copper fiber

Photo3-2 Initial crack test results for Cu+N fiber 0.1%

Photo3-3 Initial crack test results for Cu+PP fibers 0.05%

4. Conclusion

The findings of this study are as follows.
(1) With the addition of both copper and chemical fibers, fresh properties equivalent to those of mortar with only copper fibers can be ensured.
(2) The addition of chemical fibers generally results in a decrease in mortar compressive strength and flexural strength compared with copper fibers alone, but strength development is unchanged with the addition of up to 0.05% polypropylene fibers.
(3) When sprayed, sufficient thickness can be obtained using the formulations examined in this study.
(4) Initial cracking is not supressed with the formulations examined in this study. Among the tested formulations, the one with added polyproplene fibers added showed best results at controlling initial cracking. However, further study of cracking is needed in the future.

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