Available online at www.sciencedirect.com

Pergamon

SCIENCE DIRECT®

Cement and Concrete Research 34 (2004) 1981–1986

CEMENT AND CONCRETE RESEARCH

Investigation of brucite-fiber-reinforced concrete

Liu Kaiping[a,b,*], Cheng Hewei[b], Zhou Jing'en[a]

[a]School of Material Science and Engineering, Xi' An Jiaotong University, Xi'an, Shaan Xi 710049, PR China
[b]Department of Material Science and Engineering, Chang'An University, 126# Yan Ta Road, Xi'an, Shaan Xi 710054, PR China

Received 19 September 2003; accepted 17 February 2004

Abstract

Laboratory experiments were made on the brucite-fiber-reinforced concrete composites. Effects of brucite fiber grades and the dosage on flexural strength, compressive strength, impact strength, sulfate corrosion resistance and the slump, cohesiveness, as well as the water retentiveness were also investigated. Different water reducers were tested. The particle-size characteristics of brucite fibers, the densities of the concrete, and the viscosities of the fiber/water-reducer suspensions were also measured. Results show that proper addition of brucite fibers in concrete can improve the mechanical properties, especially the flexural strength. In the test, the optimum quantity was about 0.5 wt.% of concrete. With the dosage increase of brucite fibers in concrete, the fluidity and the density of the concrete decrease. The performance of the concrete strengths is the collective interactions of the fiber reinforcement and the density reduction. The aspect ratio and the surface area of brucite fibers are the important affecting factors to the workability and the mechanical properties of the fiber concrete. Larger aspect ratios and smaller surface areas benefit the reinforcement. Water reducers with lower fiber suspension viscosities are favorable in improving the workability and strengths of the brucite fiber concrete.

Keywords: Brucite fiber; Concrete; Composite; Physical properties; Fiber reinforcement

1. Introduction

Concrete is considered a brittle material as it has low tensile strength and failure strain. It is difficult to suppress the formation and growth of cracks developed therein and is apt to be fractured by tensile load or dynamic load. To resolve these drawbacks and to prolong the service duration of concrete, fiber-reinforced concrete has been developed in which fibers are incorporated to improve the mechanical properties.

Fiber-reinforced concrete, or fiber concrete, is a composite. It takes the advantages of the high compressive strength of concrete and the high tensile strength of fibers. Furthermore, it increases the energy absorption capacity of concrete through the adhesion peeling off, pulling out, bridging, and load transmitting of fibers in the concrete, and improves the ductility, toughness, and impact strength. The fibers for concrete reinforcement at present include steel fibers, glass fibers, carbon fibers, synthetic organic fibers, as well as Calcia/alumina fibers [1], wollastonite fibers [2], ceramic fibers [3], etc. However, it is not common to use brucite fibers as the reinforcement in concrete until now.

Brucite fiber is a naturally occurring fibrous mineral abundant in China [4]. The main chemical composition is $Mg(OH)_2$. Brucite fiber is quite different from asbestos in chemical compositions, crystal structures, and chemical properties. After the systematic tests, including animal test, investigation of people's epidemics, solubility of the mineral, and the organism durability, etc., it has been proved that brucite fiber is a harmless mineral to human body [5,6].

Brucite fiber has some excellent properties, such as acceptable mechanical performance, low solubility (about $10^{-19.5}$–$10^{-16.5}$ in water [7]) and antialkaline property, fiber-splitting and dispersing properties, etc. It is compatible with the silicate cement and can reinforce cement products. Results of the performance of the brucite fiber/concrete composite and the related factors affecting the

* Corresponding author. Department of Material Science and Engineering, Chang'An University, 126# Yan Ta Road, Xi'an, Shaan Xi 710054, PR China. Tel.: +86-2985408055(h), +86-2982339076(O); fax: +86-2985261532.

E-mail address: liukapin@163.com (L. Kaiping).

0008-8846/$ – see front matter
doi:10.1016/j.cemconres.2004.02.018

Table 1
Chemical analysis of brucite fibers

	MgO	H_2O^+	H_2O^-	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO
wt.%	61–65	28.02	0.08	2–6	0.6–1.9	1–3	0.2–0.3	0.1–0.2

possible application of brucite-fiber-reinforced concrete are reported.

2. Experimental

2.1. Raw materials

Brucite fiber was obtained from Shaan Nan Asbestos Mine, Shaan Xi Province. It was in white gray fibrous morphology with a density of about 2.4 g/cm^3. The tensile strength and the Young's modulus are about 932 MPa and 14.7–19.6 GPa [7], respectively. Its chemical composition provided by the mine is listed in Table 1.

In this paper, two grades, that is, the grade S and grade L of brucite fibers were used. Their particle size characteristics and SEM photos are shown in Table 2 and Figs. 1 and 2. The particle size distribution and the specific surface area data were obtained by a GSL-101B laser diffractive particle analysis instrument. The sieve analysis of the fibers was carried out with a set of F500-I type standard sieves. To obtain the statistical aspect ratios, 20 fibers of each grade were measured with a JSM-5800 scanning microscope.

Cement was the 425$^\#$ ordinary silicate cement from Yao Xian Cement. The fine aggregate is the river sand with the fineness modulus 2.4 and was washed and dried before use. The coarse aggregate is the river pebble with a continuous particle size grading from 2.5 to 25 mm. Its apparent density was 2.64 g/cm^3, and bulk density was 1.27 g/cm^3. The reagent grade chemical agents Na_2SO_4 powder and 0.5 mol/l H_2SO_4 solution were used in the sulfate resistant corrosion test according to the GB2420-81 standard. Three types of water reducers were used in the formula. They were DNF, HB-2000, and OT. DNF (1$^\#$) is a naphthalene-based high-concentration and high-efficiency superplasticizer. HB-2000 (2$^\#$) is an amino sulfonic-based high-efficiency and retarding superplasticizer. OT (3$^\#$) is an anionic surfactant with the chemical formula of $NaSO_3C_2H_3(COOC_8H_{16})_2$.

Table 2
Particle size parameters of brucite fibers

Brucite grade	Sieve analysis (wt.%)			Aspect ratio		Specific surface area (cm^2/g)
	>1.4 mm	>0.4 mm	Sieve bottom	Range	Average	
S	32	48.5	19.5	24–176	95	150.3
L	12	35	53	14–143	53	239.2

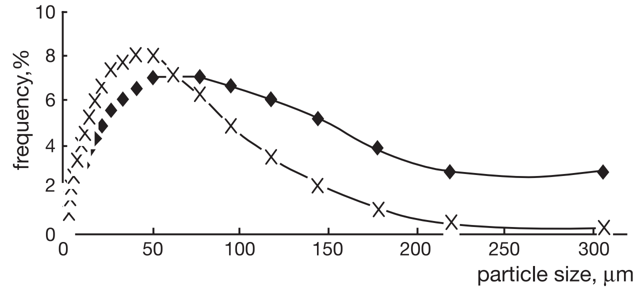

Fig. 1. Particle size distribution of brucite fibers; ×: grade L; ◆: grade S.

2.2. Methods

The concrete was prepared on the mass ratio of cement/sand/pebble/water = 1:2.05:2.4:0.5. The quantity of water reducer in concrete was 0.5, 0.75, and 0.5 wt.% of cement for 1$^\#$, 2$^\#$, and 3$^\#$, respectively. The brucite fiber was added in different quantities. The preparation procedure was as follows.

The brucite fiber and a water reducer were put into water, stirred with D90-2F type electric mixer for 5 min to form a suspension. Meanwhile, the sand, pebble, and cement were blended in a mixer. Afterwards, the dry material and the suspension were mixed, poured into a mould, shaken on a vibration table, and then cured for different periods.

The slump, cohesiveness, and the water retentiveness as well as the compressive, flexural strengths of the concrete were determined by the GB8076-1997 and GB8077-1987 standard methods. The sulfate corrosion resistant factor was obtained with the GB2420-81 method. The impact strength was measured on a JB-5-type impact test machine. The impact energy range was 29.4 J. The samples with dimensions of 11 × 40 × 160 mm for impact test were prepared with 2.5- to 4-mm pebbles as the coarse aggregate. The average value of three samples was taken as the result for each specimen.

3. Results and discussion

3.1. Grades of brucite fibers

Table 3 shows the influences of brucite grades on the concrete workability and the sulfate corrosion resistance.

Table 3
Workability of the concrete

Brucite fiber	Slump (mm)	Cohesiveness	Water retentiveness	Corrosion resistant factor	W/C	Water reducer
Grade S	20	A	C	0.9	0.5	1$^\#$
Grade L	12	C	A	0.87	0.5	
Control sample	34	B	C	0.79	0.42	

Table 4
Effects of brucite fiber grades to the strengths of the concrete

Brucite fiber	Compressive strength (MPa)		Flexural strength (MPa)		Water reducer
	7d	28d	7d	28d	
Grade S	24	30	4.4	5.2	$2^{\#}$
Grade L	18	28	3.5	4.6	
Control sample	22	26.5	3.2	3.7	

The fiber's dosage was 0.5 wt.% of the concrete. The A, B, and C in the table represent the good, moderate, and bad behaviors, respectively, of cohesiveness or water retentiveness. The control sample is the concrete without brucite fibers in it. The W/C is the mass ratio of water to cement.

Table 4 shows the mechanical strengths of the concrete.

From the comparison of brucite-fiber-reinforced concrete and the controlled samples in Table 3, it is obvious that the addition of brucite fibers decreases the flowability of the concrete, probably because of the large surface areas and strong absorption capacities of the fibers.

Table 4 shows that brucite fibers can generally increase the compressive and flexural strengths, especially the latter. This is accordance with the test result of brucite-fiber-reinforced cement mortar [8].

Table 5
Densities of the concrete reinforced with different grades of brucite

Brucite	Density of concrete (10^3 kg/M^3)	Notes
Grade S	2.30	$2^{\#}$ water reducer
Grade L	2.18	
Control sample	2.29	

From Tables 3 and 4, it is also clear that the slump, the cohesiveness, and the sulfate corrosion resistant factors, as well as the compressive and flexural strengths of the grade S brucite-fiber-reinforced concrete are better than those of the grade L, except for the water-retention capacity. The results indicate that the concrete reinforced with grade S brucite fiber has higher mechanical properties and better flowability.

The possible reason of different mechanical strengths and the workability of the concrete reinforced with different grades of brucite may lie in their differences of physical properties. From Table 2 and Figs. 1 and 2, the grade S brucite fiber has a wider particle size distribution and a larger aspect ratio than grade L. This is perhaps the reason why it could reinforce the concrete more effectively. Its specific surface area is smaller, which makes it absorb less water, so that the fluidity of the concrete was better. The result tells us that in the reinforcement of brucite fiber to concrete, the

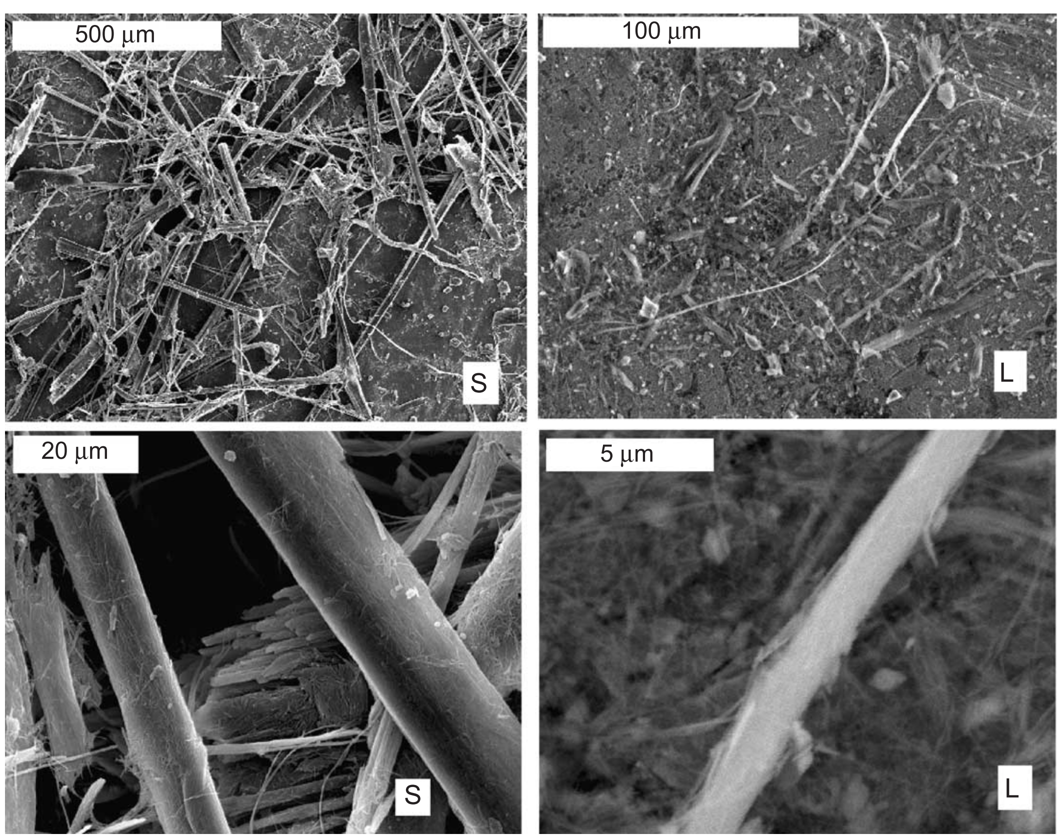

Fig. 2. SEM photos of brucite fibers; S and L are the brucite grades.

Table 6
Impact strengths of the fiber concrete

Dosage of grade S fibers (wt.%)	Impact strength (J/M^2)		Water reducer	W/C
	7d	28d		
0	21	25.5	1#	0.42
1	24.5	28	1#	0.5

aspect ratio and the surface area of fibers are the important factors. For better reinforcement, the brucite fibers should have a larger aspect ratio and a smaller surface area.

In Table 3, the sulfate corrosion resistant factor of the concrete was increased by about 14% when brucite fibers were in it, meaning that, although the W/C ratio of the concrete without brucite fibers is lower, the sulfate corrosion resistance of the brucite-fiber-reinforced concrete is stronger.

The difference of sulfate corrosion resistance between S and L grade brucite-fiber-reinforced samples may have something to do with the density of the concrete. The densities of the fiber concrete are listed in Table 5. In the table, the concrete reinforced with grade S brucite has a higher density, revealing that it has lower porosity, so that it has better corrosion resistance.

3.2. Dosages of brucite fibers

3.2.1. Impact strength of concrete

Table 6 shows the test result of the impact strengths of the concrete with 0.5 wt.% grade S brucite fibers.

In the table, after the addition of brucite fibers, the impact strength of the concrete was raised by about 17% for 7d and 10% for 28d, respectively. This indicates that the brucite fiber can also reinforce the dynamic mechanical properties of the concrete.

3.2.2. Workability

Table 7 shows the effects of the dosage of grade S brucite fibers to the workability of the concrete at the conditions of W/C = 0.5 and 1# water reducer.

The result shows that the slump and the cohesiveness of the concrete decrease with the dosage increase of brucite fibers. The water-retention capacity varies in a contrary tendency. The reason also lies in the large surface areas and strong absorption capacities of the fibers. When the dosage of brucite fiber increased, more water was absorbed by it, leading to the decrease of the fluidity and the increase of the water retentiveness of the concrete.

Table 7
Effects of brucite dosage to the workability of the concrete

Dosage of fibers (wt.%)	Slump (mm)	Cohesiveness	Water retentiveness
0.5	20	A	C
1.0	17	A	A
1.5	9	C	A

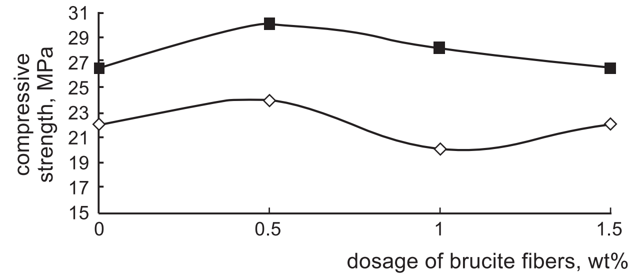

Fig. 3. Compressive strength of brucite fiber concrete; ◇: 7d; ■: grade d.

From the workability of the concrete, the best quantity of brucite fibers should be around 1.0 wt.% of the concrete where the cohesiveness and the water-retention capacity are good, and there is not much loss in the slump.

3.2.3. Compressive and flexural strengths

Figs. 3 and 4 show the relationships between the dosage of grade S brucite and the compressive and flexural strengths at the 2# water-reducer condition.

The variation tendencies of the compressive strengths and the flexural strengths versus the dosage of brucite fibers change in a similar way. When the brucite fiber was added, the strengths were increased at first, and then went down. As the brucite dosage reached 1.5 wt.%, the compressive strengths of both 7d and 28d got almost to that of unreinforced ones, and so did the flexural strength of 7d. The only exception is the 28d's flexural strength that was about 24% higher than the original one. The optimum dosage is about 0.5 wt.%, where the compressive and flexural strengths were increased by about 13% and 41% for 28d, and about 10% and 38% for 7d.

What is noticeable is that, at the 1.0 wt.% brucite dosage, the 7d compressive strength and the 7d flexural strength were obviously declined, implying that the early mechanical strengths of the concrete reinforced with 1.0 wt.% brucite fibers are lower. In comparison to the workability test in Section 3.2.2 where the 1.0 wt.% brucite fibers is the best quantity for workability, it reveals that, at the 1.0 wt.% brucite fiber doses with 2# water reducer, the hardening of the concrete was postponed.

Fig. 5 shows the relationship between the densities of the concrete and the dosage of the S grade brucite fibers. The

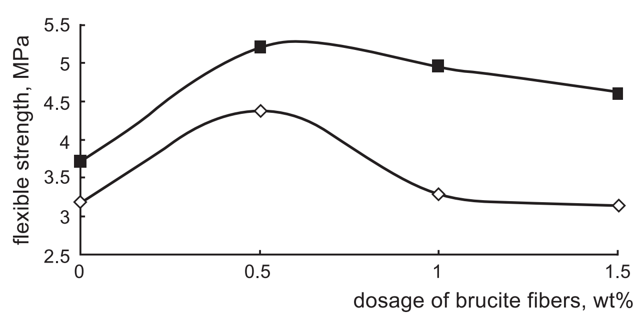

Fig. 4. Flexural strength of brucite fiber concrete; ◇: 7d; ■: grade d.

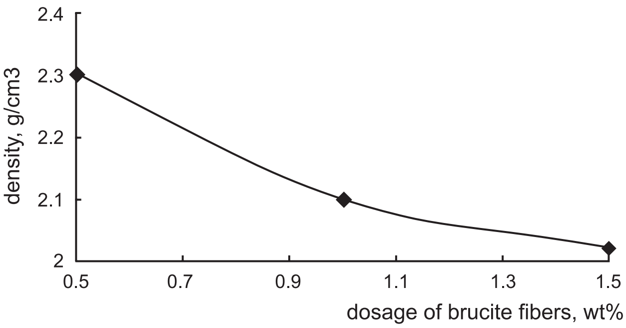

Fig. 5. Density of brucite fiber concrete.

variation tendency in Fig. 5 is almost similar to that of slumps in Table 7. Thus, we have reason to believe that the fluidity is an important factor affecting the densities of the fiber concrete.

The performance of the concrete strengths could be the collective interactions of the fiber reinforcement and the density reduction. At the brucite doses of less than 0.5 wt.%, the function of fiber reinforcement may dominate. When the doses of brucite were higher than that, the action of density reduction may play a leading part.

3.3. Effects of water reducers

Because the addition of brucite fibers may affect the fluidity for the large surface areas and strong absorption capacities, the water reducers are very important additives for the brucite/concrete composite system. Table 8 shows the workability of the concrete with different water reducers at the grade S brucite dosage of 0.5 wt.%.

From the table, the addition of water reducers can increase the flowability of the concrete, although with different slump values. The water reducer $1^{\#}$ has the highest slump value and best cohesiveness in the three, but its water retentiveness is the worst. The water reducer $3^{\#}$ is contrary to the $1^{\#}$ in slump and water retentiveness. In the comparison of the comprehensive workability parameters, the water reducer $2^{\#}$ should be the best choice in the brucite/concrete system.

To study the cause of workability differences of different water reducers, viscosity measurements of the fiber/water/water reducer system were conducted by putting brucite fibers into the water-reducer solutions (the mass ratio of fiber/water/water reducer was identical to that in the concrete), agitating for 20 min with a D90-2F electric motor, then measuring the viscosity of the suspension with a NGJ-1-type viscosity meter. The average value of three records of each sample was taken as the result (Table 9).

Table 8
Concrete workabilities with different water reducers

Water reducer	Slump (mm)	Cohesiveness	Water retentiveness	W/C
No water reducer	13	C	A	0.52
$1^{\#}$	20	A	C	0.5
$2^{\#}$	18	A	A	0.5
$3^{\#}$	15	B	A	0.5

Table 9
Viscosity of brucite fiber suspension

Water reducer	$1^{\#}$	$2^{\#}$	$3^{\#}$
Brucite grade L (mPa s)	540	410	820
Brucite grade S (mPa s)	130	58	420

Table 10
Mechanical strengths of concrete with different water reducers

Water reducer	Compressive strength (MPa)		Flexible strength (MPa)	
	7d	28d	7d	28d
$1^{\#}$	18	24	2.5	3.1
$2^{\#}$	24	30	4.4	5.2

From Table 9, the viscosity sequence of fiber suspensions is $2^{\#} < 1^{\#} < 3^{\#}$ for water reducers, and grade S < grade L for brucite fibers. The lowest viscosity appears in the suspension of grade S brucite with $2^{\#}$ water reducer. The viscosity performances of water reducers explain the reason why in Table 8, the concrete with $3^{\#}$ water reducer had a good water retention capacity and a low slump value; so do the viscosity performances of grade L and S, where they were the origin of different slump values and water retention behaviors in Table 3. The differences in viscosity of grades S and L brucite fibers may also be originated from their particle size characteristics in Figs. 1 and 2, and Table 2.

Because the high viscosity means the abundant fiberization of the fibers and the great increase in fiber surface areas and is unfavorable to the fluidity of the concrete, although it may benefit the water retentiveness, it is preferable not to have a very high viscosity in the operation. From Table 9, because the viscosities of grade S brucite with $1^{\#}$ and $2^{\#}$ water reducers are relatively lower, it is necessary to do the concrete strength experiment in these conditions. The results are listed in Table 10. Here, the dosage of grade S brucite fiber is 0.5 wt.%, and the W/C ratio is 0.5.

The result shows that the concrete with water reducer $2^{\#}$ is better than that with $1^{\#}$ in mechanical properties. Both the compressive strengths and the flexural strengths of 7d and 28d are higher. This could be ascribed to its lower viscosity of the fiber suspension (Table 10), possibly leading to the better fluidity and the compacter structure of the concrete, as well as the stronger combination between the brucite fibers and the other concrete ingredients.

4. Conclusion

(1) Proper addition of brucite fibers can increase the compressive, flexural, and impact strengths as well as sulfate corrosion resistance of the concrete, especially the flexural strength. In the test, the optimum dosage was about 0.5 wt.% of the concrete.

(2) With the dosage increase of brucite fibers, the fluidity and the density of the concrete decrease, while the water retentiveness goes up, possibly because brucite fibers have large surface areas and strong absorption capacities, which control the fluidity, hence, the density of the fiber concrete. The performance of the concrete strengths is the collective interactions of the fiber reinforcement and the density reduction.
(3) The aspect ratio and the surface area of brucite fibers are important affecting factors to the workability and the mechanical properties of the fiber concrete. Larger aspect ratios and smaller surface areas benefit the reinforcement.
(4) Water reducers can affect the workability and the strengths of the fiber concrete system. By comparison, those with lower fiber suspension viscosities are favorable in improving the workability and the strengths of the brucite fiber concrete.

Acknowledgements

The authors wish to thank the financial support from the Transportation Fundamental Research Program of China.

References

[1] K.-Y. Yon, B.S. Mitchell, S.A. Dann, J.A. Koutsky, Introduction of new reinforcement for cementations materials calcia/alumina (CA) fibbers by the inviscid-spinning (IMS) process, Cem. Concr. Compos. 15 (3) (1993) 165–172.
[2] N.M.P. Low, J.J. Beaudoin, Flexural strength and microstructure of cement binders reinforced with wollastonite microfibers, Cem. Concr. Res. 23 (4) (1993) 905–916.
[3] Y. Ma, M. Tan, Durability and the mechanical properties of the ceramics fiber cement matrix composite, J. Chin. Ceram. Soc. 28 (2) (2000) 105–110.
[4] R. Zheng, K. Wei, Utilization and development of the brucite resources in China, China Mines Ind. 7 (2) (1998) 21–23.
[5] F. Dong, P. Wan, K. Zhou, J. Liu, S. Luo, Environmental safety investigation on fibrous brucite, Bull. Mineral. Petrol. Geochem. 16 (1) (1997) 43–46.
[6] J. Deng, Y. Wu, S. Zhao, Y. Song, F. Dong, G. Li, Effects of acid treated fibrous brucite on hemolytic activities, Ind. Health Occup. Dis. 26 (2) (2000) 76–77.
[7] F. Dong, Z. Pan, P. Wan, K. Zhou, Physical properties investigation of fibrous brucite (FB) in the south of Shaanxi, J. Southwest Inst. Technol. 10 (4) (1995) 5–15.
[8] K. Liu, J. Zhou, Experimental study of brucite fiber/cement matrix composite, China Concr. Cem. Prod. (3) (2003) 32–35.