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Application of magnesium phosphate cement affixed carbon fiber sheet to strengthen reinforced concrete beam and slab

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ABSTRACT

The organic glue currently used to affix the carbon fiber sheet to strengthen the reinforced concrete has a very low softening point. Therefore, a new type of non-organic glue magnesium phosphate has been developed to replace the epoxylite organic glue to be used for strengthening of concrete beam and slab using the carbon fiber sheet. This paper introduced the types of non-organic glues and carried out double shear tests on the carbon fiber sheet affixed onto the surface of the concrete surface using the magnesium phosphate. It was proved that the high resistance of magnesium phosphate cement to high temperatures could meet the engineering demand. Through double shear test on concrete tests blocks affixed with carbon fiber sheet and the variation of compressive strength of the new type of non-organic glue in various temperatures will both be described to demonstrate that the application of new-type non-organic glue to affix the carbon fiber sheet to strengthen concrete beam is effective. Practice has also proved that the resistance to high temperature of the new-type inorganic magnesium phosphate cement is satisfactory and the frame structure which has been strengthened using carbon fiber sheet affixed onto the structure using new-type of inorganic magnesium phosphate cement has remarkably improved bearing capacity and resistance to high temperature.

KEYWORDS

Magnesium phosphate cement; Carbon fiber sheet; Reinforced concrete; Frame structure; Strengthening.

INTRODUCTION

The carbon fiber sheet strengthening technology is one of the prevailing structural reinforcement and strengthening technologies in China and foreign countries. It refers to application of high-performance binder to affix the carbon fiber sheet onto the structural members, to allow the two to work together. However, the fire resistance of carbon fiber sheet strengthened beam is quite poor in fire accidents: On one hand, the carbon fiber sheet easily gets oxidized in fire and the oxidization aggravates as temperatures goes up, resulting in noticeable drop of its performance; on the other hand, the glue used for affixing carbon fiber sheet is highly inflammable and its strength starts to drop when temperature exceeds 60 and it almost losses all the strength when the temperature reaches 120 [1-4]. In accordance with the fire resistance test conducted on concrete structures strengthened using the carbon fiber sheet, the carbon fiber sheet affixed onto the surface of the concrete is easily burnt thoroughly when the fire protection fails. The failure of the glue line and oxidization of CRPR both mean that the carbon fiber sheet stops functioning, which leads to strengthening failure and makes the strengthened structure in the fire more vulnerable. Studies [5-6] have indicated that even when rigorous fire protection measures have been taken, the epoxylite glue can still easily reach its softening temperature.

The temperature of a building may reach above 1,000 in case of fire. If insufficient attention is paid to the resistance to high temperature of the structure strengthened by carbon fiber sheet affixed to it, the carbon fiber sheet will easily come off the concrete in case of fire and will not be able to function any more. To improve the glue's resistance to high temperature, this paper presents the real case of strengthening of a frame structure project, and conducted tests to study the application of non-organic glue affixed carbon fiber sheet for reinforcement in a frame structure project. Through double shear test, the adhesive property of carbon fiber sheet affixed using non-organic glue was studied.

PROJECT PROFILE

The original building is a complex one of the concrete frame structure with 1 storey underground and 6 stories aboveground located in Wuhou District, Chengdu. It has already been capped, with the height of the ground floor being 4.5 meters and that of the 2nd through 6th floor being 3.2 meters. The total height of the entire building is 20.5 meters. Now the plan is to change the use function of the building from a complex building to an apartment building. The employer asks for construction of a part of the building outside of the original one with the same structure and the same number of stories. Fire accident is a high-frequency accident. The employer proposed very strict requirements on fire resistance of the building. Change of the use function indicates change of load of the building. Therefore, to guarantee the old and new buildings can bear load together and meet the new use function requirements, the original building should be expanded and strengthened.

The appraisal conducted by a testing company indicated that some of the beams and floor slabs of the original building did not meet the strength and rigidness requirement and should be strengthened. According to the requirement of the employer, knocking and chiseling of the building should be kept to the minimum and the fire resistance should be improved. However, the glass transition temperature of the epoxy resin glue commonly used for strengthening is only 60 to 80 [7], which cannot meet the requirements on fire resistance. Hence, through comprehensive consideration, the new-type inorganic glue magnesium phosphate cement was chosen to affix carbon fiber sheet to strengthen and reinforce the beams and floor of the original structure.

TYPE OF THE INORGANIC GLUES

The inorganic glues used in replacement of ordinary epoxylite glues include alkali-activated cementing materials, magnesium oxychloride cement and cement based composite material.

Alkali-activated cementing materials

Alkali-activated cementing materials [8] refer to the binding materials formed from aluminosilicate raw materials activated using the alkali activator. The alkali-activated cementing materials include low polymer and alkali slag binding material, which can respectively resist temperatures of 1,000~1,200 and 600~800 . However, clay, one of the raw materials used to prepare low polymer, is expensive and may generate contaminant during sintering. Therefore, alkali slag material becomes another hot topic of domestic and foreign researchers following low polymers.

Magnesium oxychloride cement

Magnesium oxychloride cement was invented by a Swedish scholar named Sorrel [9] in 1867. It is an air hardening binding material made up of lightly roasted MgO, $MgCl_2$ and H_2O in proper proportions. It enjoys advantages such as high mechanical strength, quick setting and hardening, soft alkaline, low corrosivity, satisfactory cohesiveness, high abrasive resistance and anti-flaming and heat insulation property. It has many disadvantages, among which there are scum, buckling deformation, poor water-proof performance and cracks. Such advantages hinder the development of magnesium oxychloride cement seriously.

Cement based composite material

Cement based composite material was developed by Li [10] of the University of Michigan in early 1990's. It is a high performance fiber-reinforced composite material (cement based composite material (ECC)) made up of cement, fine aggregate, fiber, water, and active mineral admixtures such as silica fume and coal ash. It enjoys advantages such as high mechanical strength, high tenacity, satisfactory shearing properties and excellent strain hardening property.

New-type inorganic glue

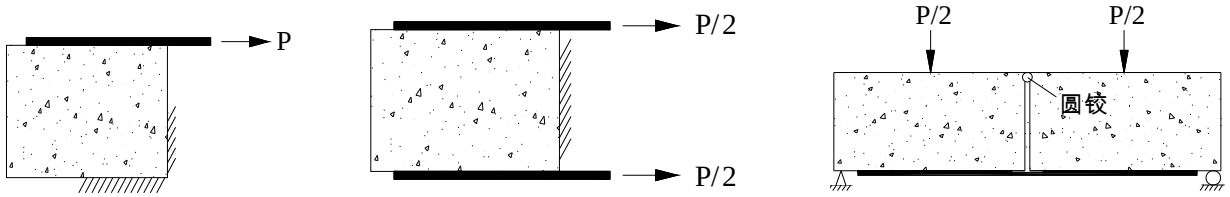
Magnesium phosphate cement belongs to the acid-alkali cement system. Acid-alkali cement was firstly invented in the mid-nineteenth century and is prepared by mixing acid or acid-base powder with acid containing liquid to produce salt with gelling property. It falls into the category of special binding material.

PROPERTY OF THE MAGNESIUM PHOSPHATE CEMENT

Test scheme of shear performance of carbon fiber sheet and concrete after affixing

In the concrete structural members strengthened using carbon fiber sheet affixed to it, the bond stress on the interface between the sheet and concrete mainly includes shearing stress. As such, the study on the mechanical property of the interface between the sheet and concrete focuses on the shear behavior of the interface and the de-bonding damage resulted therefrom. Adhesive glue is the foundation to ensure co-functioning of the fiber sheet and concrete and is one of the fundamental factors impacting the working property of the interface between the sheet and concrete. So, to evaluate binding performance of the adhesive glue, the study on shear behavior of the interface between the carbon fiber sheet affixed using the glue and the concrete should be the focus.

The interface shear behavior is generally studied by conducting in-plane shear test. The test methods currently being used include simple shear test, double shear test and beam type test, as shown in Figure 1 [11]. The simple and double shear test methods are quite simple and the stress state is obvious and therefore those methods are widely used. The binding strength is now obtained through simple and double shear tests in most cases. To facilitate test and comparison, the double shear test method was adopted to study the binding performance of the new-type inorganic glue magnesium phosphate cement.



a) simple shear test b) double shear test c) beam type test

Figure 1 Sketch of test methods for interfacial bond properties

Apply the new-type inorganic glue MPB on the two sides of 70.7mm×70.7mm×70.7mm and affix a layer of carbon fiber sheet onto the two sides within an area of 70.7mm×60mm. The double shear test specimen used to affix the sheet is shown in Figure 2. The failure load could be measured using the self-developed double-shear testing device (Figure 3) and the shear strength on the interface could be obtained through Equation (1).

$$\tau = \frac{P_u}{2b_f L_f} \quad (1)$$

Where, τ——In-plane average shearing strength (MPa);

P_u——Failure load (kN);

b_f—Binding width of the fiber sheet (mm);

L_f—Binding length of the fiber sheet (mm)

Figure 2 The double shear test specimen used to affix the sheet

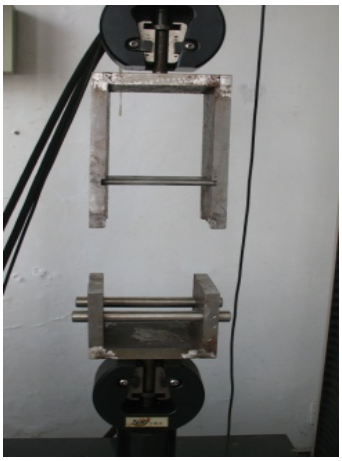


Figure 3 double-shear testing device

Resistance to high temperature of magnesium phosphate cement

Considering the requirements on resistance to high temperature proposed by the employer, the new-type inorganic glue used for the strengthening project is a newly developed alkali-activated binding material, which is made of raw materials such as over-roasted magnesium oxide, ammonium dihydrogen phosphate and borax (MPB), with a very short solidification period (20~30 minutes at room temperatures), high 3d cube crushing strength (59.60MPa), and high in-plane interface shear strength (1.29MPa). The residual compressive strength of the material, after staying in an environment with constant temperature of 600 and 800 for 3 hours, could still reach respectively 77% and 60% of the strength at normal temperatures as shown in Figure 4.

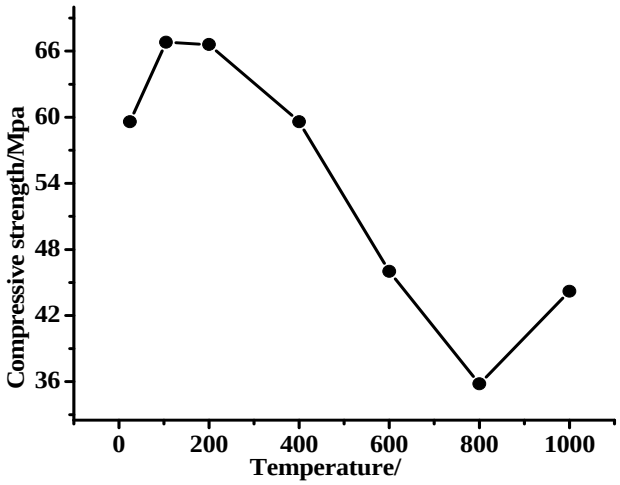


Figure 4 Compressive strength of specimens as a function of temperature

The results of the above inorganic glue performance test indicate that the new-type inorganic glue MPB could completely meet the requirements on high temperature resistance proposed by the client. The glue can co-function with the carbon fiber sheet satisfactorily.

STRENTHENING SCHEME

Material performance

The TC35-type carbon fiber sheet and magnesium phosphate cement new-type inorganic glue manufactured by Chengdu Zhuxin Trading Co., Ltd. were used for this strengthening project. The mechanical properties of the materials are shown in Table 1.

TABLE 1 The mechanics performance of carbon fiber cloth and new inorganic adhesive MPB

	carbon fiber cloth	MPB
Elongation (%)	1.76	1.95
The tensile modulus of elasticity (10^5MPa)	2.46	2500
strength of extension (MPa)	3532	30
compressive strength (MPa)	--	75
cohesive pulling strength between the cloth and concrete (MPa)	--	2.5
standard values of tensile shear strength (Mpa)	--	10

Strengthening scheme

Beam strengthening scheme: Affix 2 layers of carbon fiber sheet with width of 300mm and thickness of 0.167mm and length equaling to the net span of the beam in the sagging moment at the bottom of the beam. Affix 6 U-shaped hoops with width of 100mm and net distance of 200mm in the shear area on the two ends of the beam. The strengthening results are shown in Figure 5.

When the carbon fiber sheet is used to strengthen the hogging moment part of the beam at the juncture of the beam and column, the carbon fiber sheet should bypass the column. Carbon fiber sheet should be affixed within $4h_f$ of the beam side. If several layers of carbon fiber sheet are affixed onto the bottom of the beam, they should be cut off one by one and the inner layers should be shorter than the outer ones.

Floor slab of the original buildings of is the cast-in-place concrete with thickness of 100mm. The carbon fiber sheet is used to reinforce the original floor slab, with the strengthening results as shown in Figure 6.

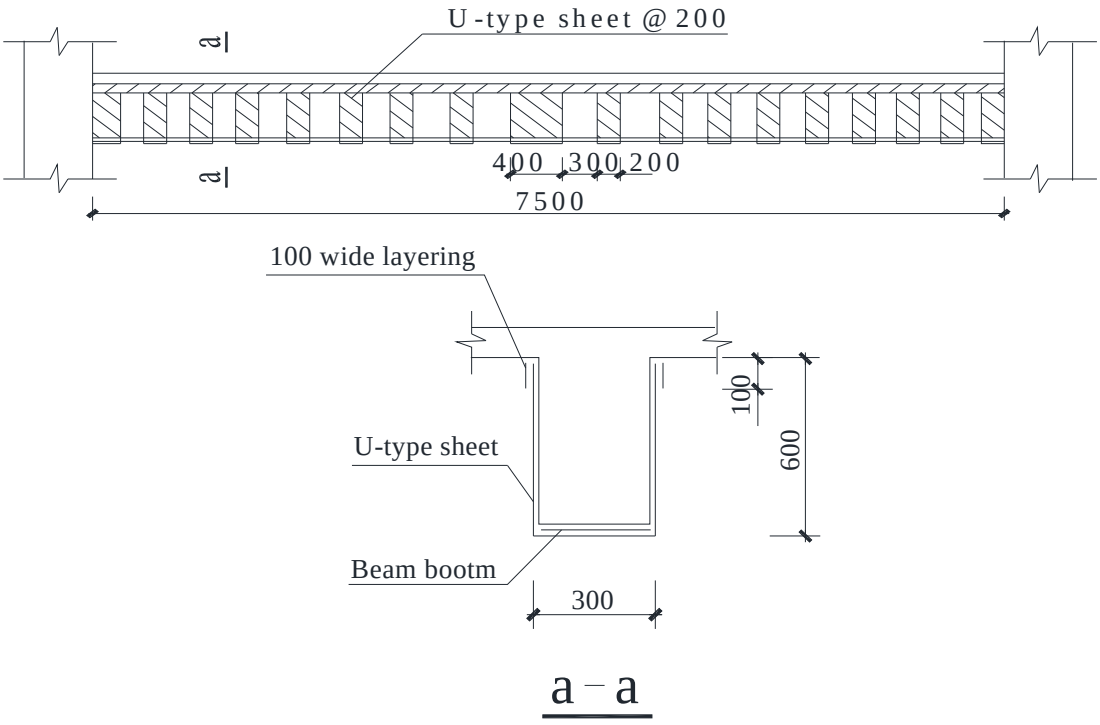


Figure 5 Schematic Diagram of Beam Strengthening

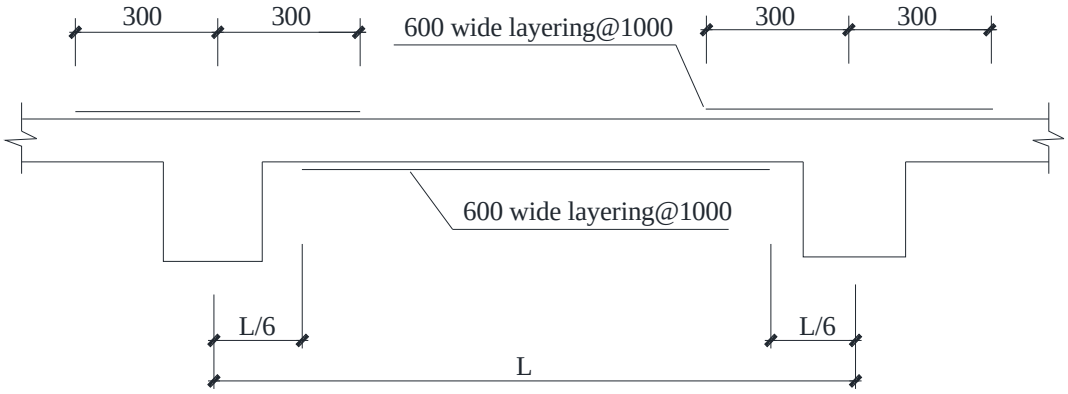


Figure 6 Schematic Diagram of Floor Stab Strengthening

CONSTRUCTION INSTRUCTIONS

Construction technique of affixing carbon fiber sheet using inorganic glue

1) Make construction preparation and unload the building.

2) Grind the concrete surface to make it smooth. Spray a little water onto the concrete surface to keep the surface wet, so as to prevent the moisture in the MPB glue from being absorbed by the dry concrete surface. This way, the outstanding binding performance of the fiber sheet on the concrete surface is guaranteed.

3) Prepare bottom layer MPB glue and fill up the unevenness to make the base plane level.

4) Clip the carbon fiber sheet to the require size.

5) Pour the properly agitated MPB glue into the drum and soak the fiber sheet in the MPB glue. Smash the fiber sheet using the drum on one direction.

6) Prepare the MPB glue and apply it evenly onto the parts to be affixed with thickness of 2mm. Affix the fiber sheet onto the concrete surface with the smashed side facing downwards. Roll the drum towards the fiber direction for several times to remove the bubbles and allow the MPB glue to soak the carbon fiber sheet. During rolling, do not damage the sheet. Apply the MPB surface glue of 2mm thick.

7) Apply impregnating resin evenly on the surface of the fiber sheet of the last layer to provide protection. After final set of the glue layers, cover the strengthened parts using moist sponge and plastic film to keep the parts wet.

Construction quality test

Carbon fiber sheet of more than 200 m2 was affixed onto the original building structure. After strengthening, the supervising organization conducted random inspection on normal bonding strength of the carbon fiber sheet, with inspection results shown in Table 2. It is obvious from Table 2 that the normal binding strength of the fiber sheet after affixing is qualified.

TABLE 2 The cohesive pulling strength of carbon fiber cloth and new inorganic adhesive MPB

NO.	Cohesive pulling strength /MPa	Failure mode	Assessment
1	2.6	cohesion damage	qualified
2	2.8	cohesion damage	qualified
3	2.7	cohesion damage	qualified

CONCLUSIONS

Through test of reinforced concrete beam strengthened via carbon fiber sheet affixed to it using new-type inorganic glue magnesium phosphate cement and its application, it is concluded that: Use of strengthening technique via inorganic glue for projects under construction or expansion projects could improve work efficiency, reduce the construction period without increasing the section size and self-weight of the beam. In addition, the bending capacity and shear bearing capacity of the strengthened structural members are improved remarkably, and can meet the requirements on bearing capacity and resistance to high temperature. The performance of the strengthened member is stable and can meet the requirement for use. The emergence of the new-type inorganic glue magnesium phosphate cement makes the development of carbon fiber sheet strengthening technique in construction industry more promising.

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