J M M
Journal of Mechanics and MEMS

ISSN: 0974-8407
© Serials Publications
9(2) 2017: pp. 211-216

Special Issue dedicated to Prof. K Y Ye edited by Z M Ye, P Liu and B Sun

MECHANICAL PROPERTY RESEARCH ON POLYMER MODIFIED FIBER REINFORCED CEMENT BASED COMPOSITES

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ABSTRACT

The brittle features of concrete, such as cracking easily and poor deformability are a significant problem that the engineering construction field is currently facing. Fiber reinforced cement based composites modified by polymer may have high ductility and good self-control over crack width, which may greatly improve the property of concrete. The present paper introduces the research on some mechanical properties of polymer modified fiber reinforced concrete under dead load and live load, and discusses deformation mechanism of this material.

Keywords: Polymer; High ductility; Fiber reinforced; Composite

1. INTRODUCTION

As a widely used construction material, the concrete's problem of drying shrinkage and brittleness becomes more obvious, along with the great raise of its compressive strength. When applied to construction, this kind of weakness of concrete mainly shows in the following three aspects: (1) the strain peak value is low, which keeps the steel used with the concrete from performing fully its mechanical properties; (2) the concrete crushes easily, which brings about a small aseismic capacity of the building structure; (3) the concrete cracks easily, which lowers the durability of concrete construction and shortens the useful time, causing a huge waste of energy resources.

A great number of scholars have done plenty of research on improving the aseismic property of concrete structure, however, due to the weakness in properties of ordinary concrete, there would be a big hidden danger to concrete structure under the live load (e.g. explosion, attack and earthquake), leading to serious structural damage that mainly is of brittleness in earthquake. In view of this weakness, high ductility, large deformability and strong durability must be a developing direction of concrete in the future. As to research on cement based concrete with large deformability, the main technique at home and abroad is adding proper filler to cement based concrete so as to improve its deformability[1~5].

2. POLYMER MODIFIED FIBER REINFORCED CEMENT BASED COMPOSITES

Polymer modified fiber reinforced cement based composites (PMFRCC) is a composite material for construction that consists of ordinary concrete as the basis, polymer with a modification effect and fiber with a reinforcement effect, which are mixed by a proper ratio. Polymer can improve the toughness of composites to a certain degree, and enhance its deformability. A little fiber added will not be enough to improve the stress-cracking property of concrete, but it is a favorable factor for concrete strength, and plays a key role in changing the cracking mode of concrete. Related experimental studies show that, after the initial crack has appeared, multiple-cracking comes about when the strain of the fiber reinforced (volume fraction of 2%) ordinary concrete rises. In the inelastic phase, the number of cracks increases a lot, but the width of a single crack does not become bigger. Under ultimate load, the crack width maintains about 60um, when the strain of material can reach to 5%. The good self-control of fiber reinforced composite material over crack width can be one of important means to enhance the durability of concrete structure.

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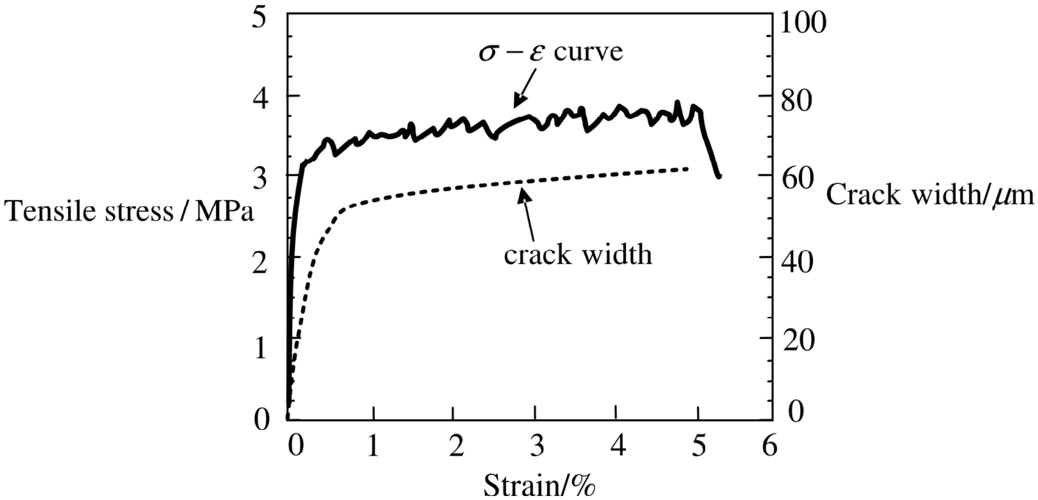

Figure 1: Tensile Stress-strain Curve and Crack width Development of PMFRCC

3. PROPERTY OF PMFRCC

3.1. Dynamic Elastic Modulus

Modulus of dynamic elasticity is an important constant for experiment on dynamic mechanical properties of material, or for optimum design of structure and its properties, and it reflects material's dynamic stress-strain relation under cyclic load in the elastic phase.

In this experiment, to test the modulus of dynamic elasticity, cubic specimen with a side length of 150mm was used and the ultrasonic pulse method was adopted. Test principle is that the propagation velocity of ultrasonic in medium concrete specimen is measured by ultrasonic testing device, and the relation between velocity of ultrasonic and the modulus of dynamic elasticity is showed in Eq. (1).

$$E_d = \rho v^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \tag{1}$$

where E_d is modulus of dynamic elasticity (10^4 MPa);

ρ is density of medium concrete specimen (kg/m^3));

v is propagation velocity of ultrasonic in concrete specimen(m/s)

μ is Poisson's ratio of concrete material, according to Concrete Structure Design Code (GB50010-2002), $\mu = 0.2$.

Table 1
The Test Value of Modulus of Dynamic Elasticity

Specimen	*Ordinary Concrete*	*PMFRCC*
Modulus of dynamic elasticity	(10^4MPa) 5.2	4.0
Percentages decreased (%)	—	28.8

3.2. Compressive Property

There is a relation, which is called constitutive relation, between stress and strain of specimen under loading. Stress-strain curve of concrete in axial compression reflects its basic mechanical properties, which is one of the main bases of studying the strength and deformation of armoured concrete structure. It has a great influence especially on elastic-plastic full range analysis of structure components, stress distribution on component interface in the ultimate state, and ductility and restoring force characteristics of seismic structure and blast-resistant structure.

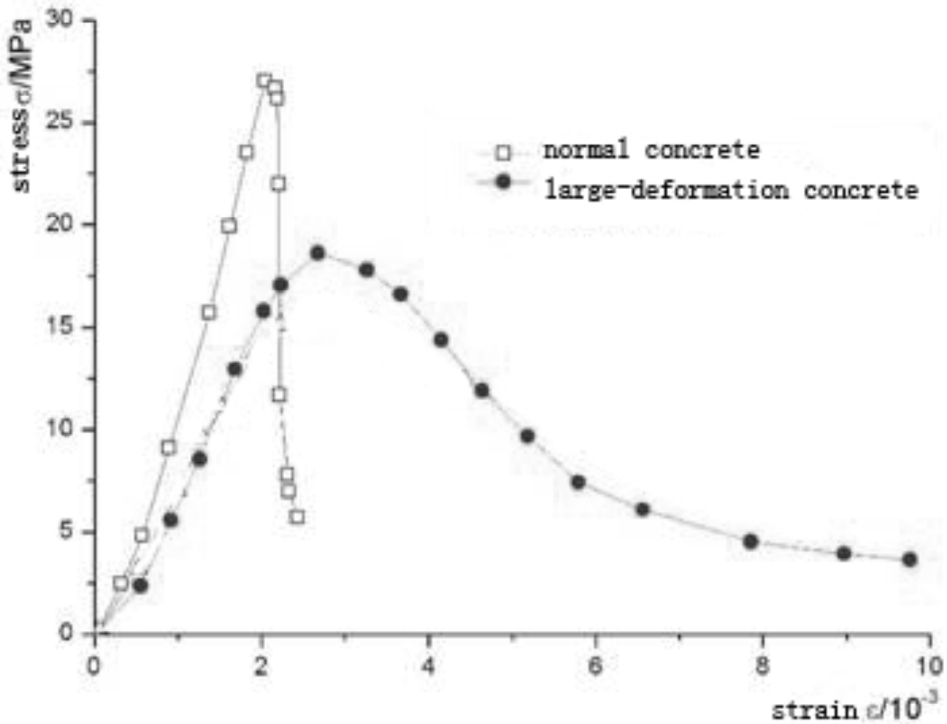

Figure 2: Schematic Stress-strain Behavior of Composites in Compression

Figure 3: Failure Mode of Ordinary Concrete in Compression

Figure 4: Failure Mode of PMFRCC in Compression

As to the constitutive relation, after the stress of ordinary component has reached to its maximum, the strain keeps the same, and the stress suddenly falls down almost without a decline stage. On the contrary, the stress's decline stage of polymer modified and fiber reinforced concrete is gentle.

As to the failure mode, when the axial pressure reaches to its maximum, the specimen of ordinary concrete fractures instantly, presenting a typical brittle failure mode. As the axial pressure increases, various kinds of small cracks appear on the whole surface of the component of polymer modified and fiber reinforced concrete, but the crack propagation trend is not obvious, and the whole process is a ductile failure[6].

3.3. Damping Property

Damping is an inherent dynamic characteristic parameter of material. Loss factor, logarithmic decrement, phase difference angle tangent, specific damping capacity, inverse quality factors are all characterization parameters of damping, and damping ratio is the most common one. Damping ratio can be expressed as:

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_0} \tag{2}$$

where ξ is damping ratio;

$\omega_2 - \omega_1$ is frequency width where the amplitude value of resonance curve is 0.707 times of the maximum;

ω_0 is resonance frequency.

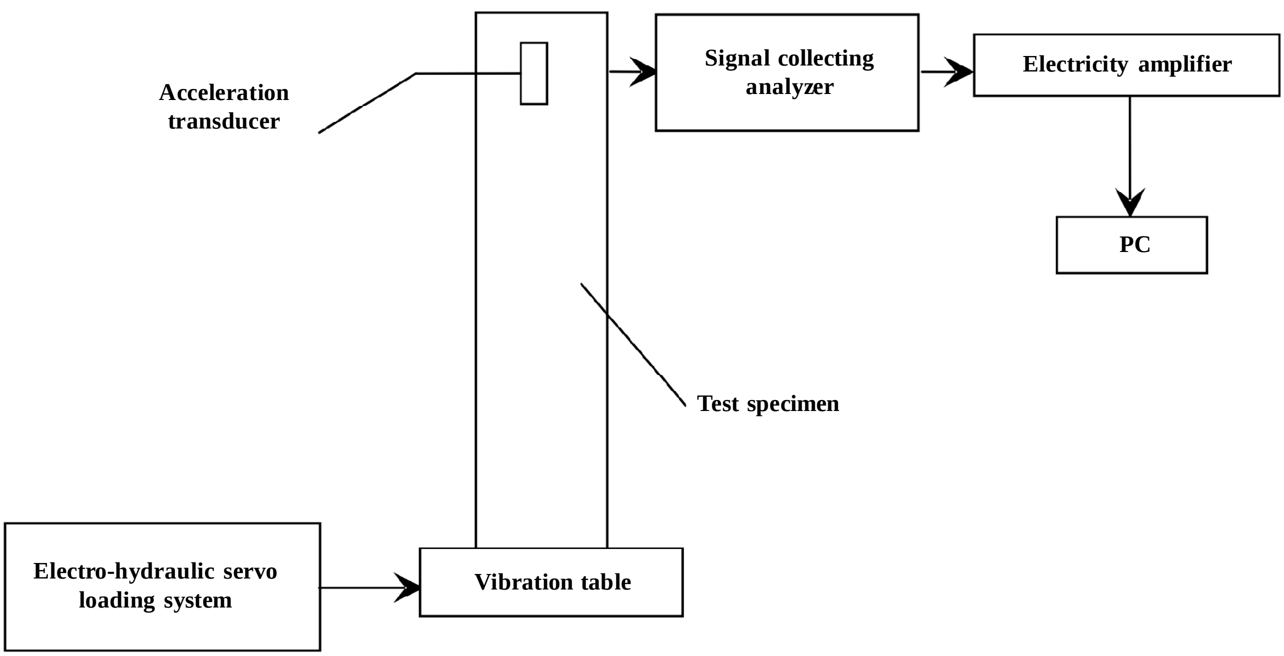

Figure 5: Experimental Equipment

Table 2
Experimental Results of Damping Test

Specimen	*Ordinary concrete*	*PMFRCC*
Damping ratio (%)	2.64	5.97
Percentages increased (%)	—	126.1

4. MECHANISM ANALYSIS

4.1. Effect of Fiber

(1) Ensure or improve the tensile strength of cement substrate: Tensile strength of cement substrate that has not been fiber reinforced is low, and often cannot be ensured for the material's inherent weakness. Adding fiber into the

material can fully guarantee the tensile strength. When the mechanical properties, physical dimension and the volume of the fiber added are appropriate, tensile strength could be obviously improved, comparing to the substrate.

(2) Have an effect of crack arrest in cement substrate: When at the plastic stage, cement substrate tends to have small cracks. During the hardening process because of the drying shrinkage, small cracks would expand and new cracks would come about, which could be prevented by adding fiber into the cement substrate so as to make a visible progress in anti-permeability and anti-freezing performance[7]. When indurated cement substrate is in tension (bending), (1) tensile stress reaches the tensile strength of concrete, one of the dangerous crack expands, resulting in brittle failure; (2) the concrete where the failure exists stops working, and the fiber on the failure section bears the tensile stress; (3) the fiber is straightened, but the crack tend not to expand for the fiber's crack arresting performance; (4) the fiber crossing the crack transmits tensile stress to the part without cracks; (5) new small cracks appear, and finally there are many small cracks, but fiber reinforced concrete does not break.

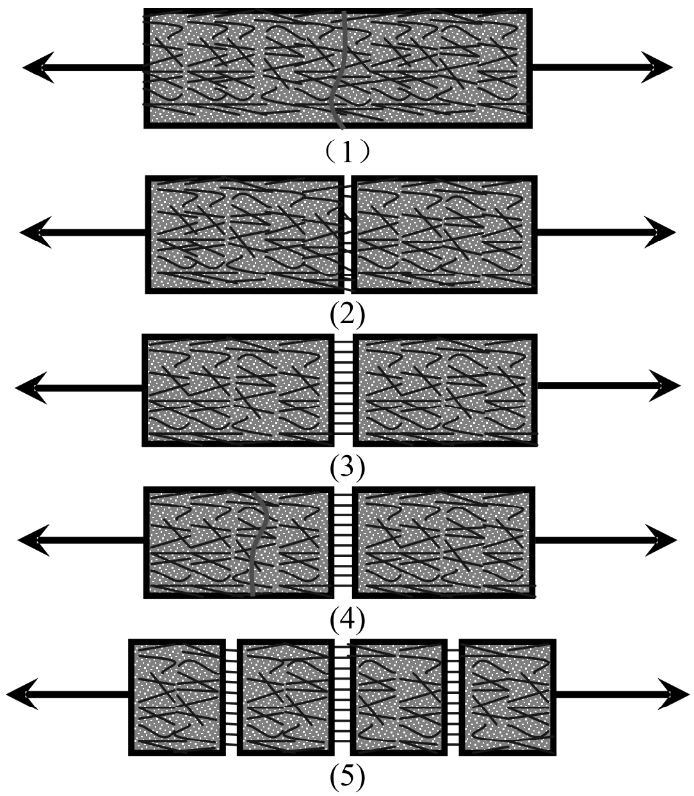

Figure 6: The Developing Process of Cracks in Fiber Reinforced Cement Based Composite

(3) Improve the deformability of cement substrate: When the fiber reinforced cement based composite is in tension (bending), even if there are a lot of dispersed cracks in it, the composite can still bear some external load and have pseudoductility, so that its toughness and impact resistance could be greatly enhanced.

4.2. Modification Mechanism of Polymer

Adding high molecular polymer into concrete can make better the properties of ordinary concrete, such as wear resistance, anti-permeability, impact resistance, and anti-crack performances, etc. This also indicates that by adding polymer the concrete would be less brittle and more flexible, which can reduce its porosity and increase its density. That polymer can raise the damping ratio is also closely related to it.

After the concrete mixture has been added by polymer emulsion and stirred uniformly, polymer particles are homogeneously dispersed in concrete. Along with the cement hydration progress, water in the system keeps combined by hydrated cement, and the latex particles are fused and integrated with each other. The pore size in concrete is ranged from dozens of nanometers to dozens of micrometers, while the size of polymer latex particle is usually 5~50μm, so that the big pores of composite structure are filled with binder and particles, and the membrane of continuous polymers is formed on the surfaces of cement hydrates and aggregates. As the water content keeps decreasing, polymer in the concrete forms into three-dimensionally continuous reticular structure, and cement paste also gets through the polymer meshes and forms a space-continuous reticular structure. These two reticular structures penetrate each other and intertwine together to form a continuous and compact matrix structure. Therefore the plasticity and flexibility of polymer concrete could be enhanced, and the surfaces between coarse aggregate and cement paste could be improved to different degrees, so as to raise the damping ratio and decrease the elastic modulus of concrete.

5. CONCLUSION AND FUTURE PROSPECT

Fiber reinforced cement based composite which has been modified by polymer, is much improved in its deformability. Its strain peak value has been raised, and its sustaining time has been prolonged when under ultimate load, and especially the cracking model of concrete presents the characteristics of plastic failure.

On the basis of the above-mentioned improvements in concrete deformability, further research on the working mechanisms of polymer and fiber is to be carried out from the micromechanics point of view[8]. In the applying aspect, polymer modified fiber reinforced cement based composite has a broad prospect, such as developing high-damping and sound-proof floor slab, flexible dissipation hinge, armoured concrete members and structures with different yield points, and so on.

Acknowledgement

The project is supported by China National Sciences Foundation under contract NSFC No.50778157.

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