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Research Article

The Study of Steel Fiber Reinforced Concrete Durability Based on Damage Mechanics

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Abstract: In order to substitute steel reinforcement with steel fiber reinforced concrete, this paper studied steel fiber reinforced concrete durability based on damage mechanics. During recent years, steel fiber reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgment in numerous engineering applications. The use of randomly distributed short fibers to improve the physical properties of a brittle or quasi-brittle matrix is an old concept. Most of the steel fiber reinforced concrete durability research just to solve a specific problem and no system of the structure performance degradation in certain circumstances. A formulation to model the mechanical behavior of high performance fiber reinforced cement composites with arbitrarily oriented short fibers. The formulation can be considered as a two scale approach, in which the macroscopic model, at the structural level, takes into account the micro-structural phenomenon associated with the fiber-matrix interface bond/slip process.

Keywords: ANSYS, damage mechanics, durability, SFRC

INTRODUCTION

During recent years, steel fiber reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgment in numerous engineering applications. Lately it has become more frequent to substitute steel reinforcement with steel fiber reinforced concrete. The applications of steel fiber reinforced concrete have been varied and widespread, due to which it is difficult to categorize. The most common applications are tunnel linings, slabs and airport pavements (Tokgoz *et al.*, 2012; Olivito and Zuccarello, 2010).

The use of randomly distributed short fibers to improve the physical properties of a brittle or quasi-brittle matrix is an old concept. Already in ancient times, people added straw or horsehair to clay for bricks. The addition of small amounts of such fibers causes an enormous increase in ductility, toughness and energy dissipation capability of the composite. In recent years, randomly distributed fiber reinforcement has been used increasingly in a variety of important civil engineering applications, such as blast resistant structures, tunnel linings and earthquake resistant construction.

Below are some properties that the use of steel fibers can significantly improve:

- **Flexural strength:** Flexural bending strength can be increased of up to 3 times more compared to conventional concrete.
- **Fatigue resistance:** Almost 1 1/2 times increase in fatigue strength.
- **Impact resistance:** Greater resistance to damage in case of a heavy impact.
- **Permeability:** The material is less porous.
- **Abrasion resistance:** More effective composition against abrasion and spalling.
- **Shrinkage:** Shrinkage cracks can be eliminated.
- **Corrosion:** Corrosion may affect the material but it will be limited in certain areas.

Currently, Steel Fiber Reinforced Concrete (SFRC) has been used more and more widely in some large-span structures, large tunnel linings, dam structures, military engineering and some other major projects. These major structural engineering is an important national social and economic infrastructure and the security work for the sustainable development of society plays a very important role. But as the same with the ordinary concrete structures, durability problem appears in SFRC in the service process when subjected to the corrosive media in environment. The neutralization of concrete and the steel corrosion are the main aspects in the durability of concrete structures and the neutralization of concrete is the prerequisite for steel corrosion. The neutralization of concrete in practical projects is the result of interaction of physical, chemical and mechanical factors. Therefore, the neutralization of SFRC under multiple factors should be investigated, which is significant for the durability design and assessment and for the further investigation reinforcement corrosion and service life prediction of SFRC structures.

Most of the steel fiber reinforced concrete durability research just to solve a specific problem and no system of the structure performance degradation in certain circumstances. Want to durability design and remaining life prediction of steel fiber reinforced concrete structure, their whole life analysis. General atmospheric environment research of steel fiber reinforced concrete durability should be around neutral model, reinforced the initial corrosion time, the protective layer rust cracking, corrosion of steel fiber reinforced concrete components bearing capacity calculation methods to expand (Wang *et al*., 2009; Singh and Kaushik, 2003; Ünal *et al*., 2007).

The early concrete strongly alkaline, its pH value is generally 12 to 13 the reinforced surface can produce a layer of passivation film to prevent corrosion of the rebar. Of the acidic substances in the atmosphere through the pores inside into the concrete from the concrete surface, the neutralization reaction occurs with the basic substance in the cement paste, reduce the concrete pH value process called concrete neutral. Neutral process of reducing the alkalinity of concrete, reinforced surface passivation film be destroyed, lost the protective effect of the reinforcement and ultimately lead to reinforcement corrosion. Practical engineering applications are difficult to determine due to the many parameters of the theoretical model is not easy. Scholars around the factors that affect the carbonation of concrete, to carry out a large number of fast carbonation test and outdoor exposure test and the actual engineering carbonation investigation and proposed predicted carbonation depth empirical model. The basic empirical model based concrete carbonation depth of carbonation is proportional to the square root of the time, to study the carbonation coefficient.

The objective of the study is to model the mechanical behavior of high performance fiber reinforced cement composites with arbitrarily oriented short fibers. The formulation can be considered as a two scale approach, in which the macroscopic model, at the structural level, takes into account the micro structural phenomenon associated with the fiber-matrix interface bond/slip process.

METHODOLOGY

The theoretical framework of damage mechanics is the mid-1970s, since the 1980s, however, the damage mechanics would have begun to be used to describe the non-linear characteristics of the concrete. Speaking from the physical mechanism of the injury is the cause nonlinear stress-strain relationship and irreversible deformation of the main reasons. Therefore, many scholars believe that the damage theory suitable for concrete constitutive model (Buratti *et al*., 2011; Nguyen-Minh *et al*., 2011).

Macroscopic mechanical properties at the macro level based on the method of continuum mechanics, the study of solid materials in a representative volume element, through visits voxels damage caused by the change of the parameters to define the injury. At this level under the definition of injury is a spatially continuous distribution, but with the time changes continuously variable, its general definition of the formula:

$$D = 1 - \frac{\varphi}{\varphi_0}$$

φ, φ_0, respectively as the material of the current and initial mechanical performance parameters, represents the stress of the material strength, elastic modulus and mass density and the material within the volume fraction of the micro-defects than or area fraction ratio.

Figure 1 shows the Kinematics at the mesoscale level. The study of damage mechanics deformable

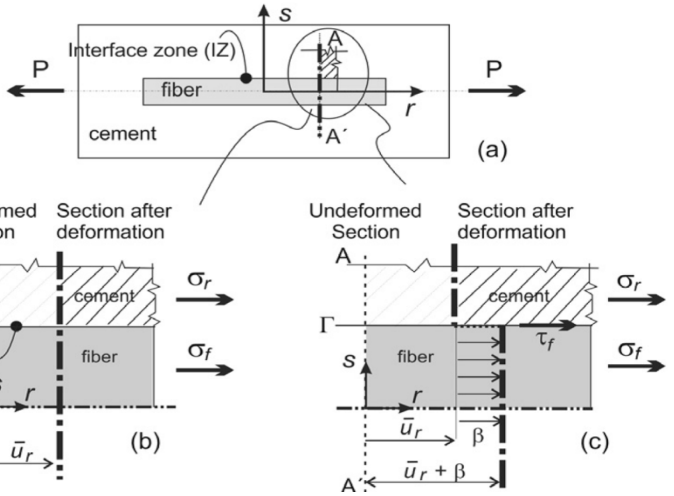


Fig. 1: Kinematics at the mesoscale level

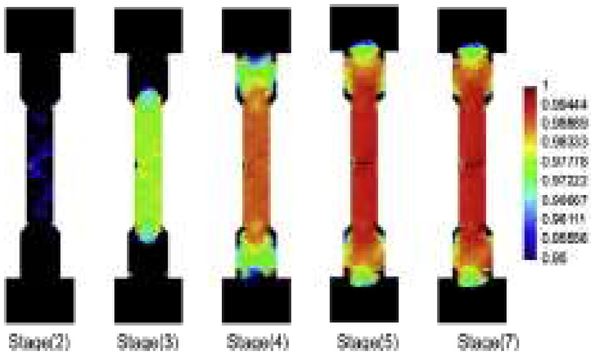


Fig. 2: HPFRC dogbone shape specimen subjected to the tensile test

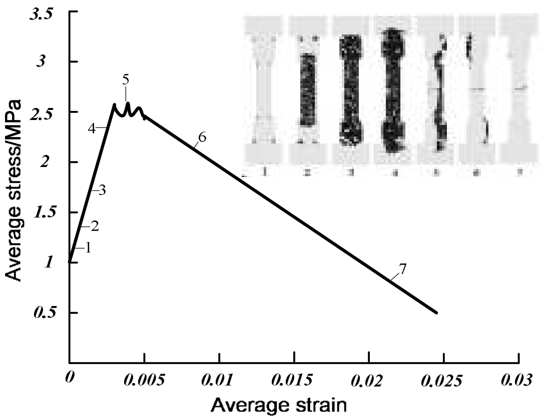
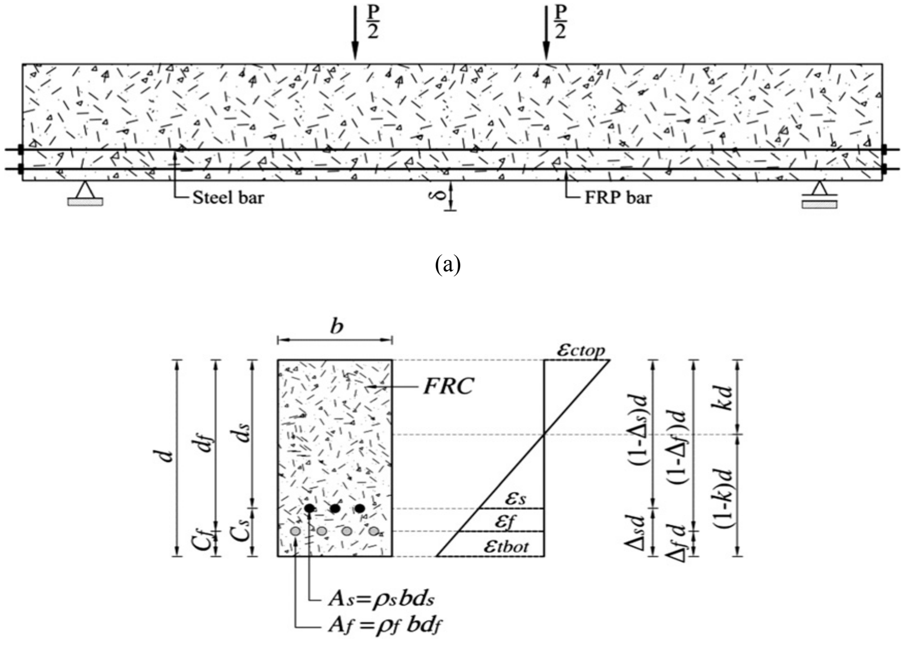


Fig. 3: HPFRC dogbone shape specimen tensile test

solids containing a continuous distribution of defects and its purpose is to determine the evolution of the damage continuous field variables. This determines its research continuum mechanical system under the ways and means, but necessary introduce mesoscopic and materials science methods to understand the causes of injury and the shape and characteristics of the micro-structure of the theories and methods of injury problems broadly can be divided into three types, namely, metal physics methods, phenomenological methods, statistical methods. A new formulation to model the mechanical behavior of high performance fiber reinforced cement composites with arbitrarily oriented short fibers is presented in J. Oliver's research (Oliver *et al*., 2012).

Figure 2 depict iso-damage color maps and illustrate different stages during the evolution of the matrix damage distribution. The formulation can be considered as a two scale approach, in which the macroscopic model, at the structural level, takes into account the meso-structural phenomenon associated with the fiber-matrix interface bond/slip process. This phenomenon is contemplated by including, in the macroscopic description, a micromorphic field representing the relative fiber-cement displacement. Then, the theoretical framework, from which the governing equations of the problem are derived, can be assimilated to a specific case of the material multifield theory.

In an attempt of overcoming these drawbacks, some researchers proposed a combination of FRP and steel reinforcements for concrete beams. In Fig. 3, there



(a)

(b)

Fig. 4: (a) Concept of FRC-hybrid reinforcing system and (b) variables involved in the analytical model

is HPFRC dogbone shape specimen tensile test. Combining these reinforcement materials and considering the minor concrete cover required for FRP, an effective reinforcement solution in terms of durability is obtained by placing the FRP bars near the outer surface of the tensile zone and steel bars at an inner level of the tensile zone. Figure 4 described the concept and analytical model of FRC-hybrid reinforcing system. The presence of steel bars in the above mentioned hybrid reinforcement system provides a significant contribution in terms of ductility and stiffness (Barros *et al*., 2012). The experimental tests where this hybrid reinforcement concept was used, in spite of being scarce, have confirmed the potentialities of this reinforcement system.

RESULT ANALYSIS

ANSYS software is a financial structure, fluid, electric field, magnetic field, the sound field analysis in one large general-purpose finite element analysis software. By ANSYS development, the world's largest finite element analysis software company, one that can, with most CAD software, interface, data sharing and exchange, such as Pro/Engineer, NASTRAN, Alogor, I-DEAS, AutoCAD and other modern one of the CAD tools in the product design (Wang *et al*., 2008).

The basic equation of motion solved by an implicit transient dynamic analysis is:

$$m\ddot{x} + \dot{c}x + kx = F(t)$$

where,

m = The mass matrix
c = The damping matrix
k = The stiffness matrix
$F(t)$ = The load vector

At any given time, t, this equation can be thought of as a set of "static" equilibrium equations that also take into account inertia forces and damping forces. The Newmark or HHT method is used to solve these equations at discrete time points. The time increment between successive time points is called the integration time step.

For linear problems:

- Implicit time integration is unconditionally stable for certain integration parameters.
- The time step will vary only to satisfy accuracy requirements.

For nonlinear problems:

- The solution is obtained using a series of linear approximations (Newton-Raphson method), so each time step may have many equilibrium iterations.
- The solution requires inversion of the nonlinear dynamic equivalent stiffness matrix.
- Small, iterative time steps may be required to achieve convergence.
- Convergence tools are provided, but convergence is not guaranteed for highly nonlinear problems.

The basic equations solved by an Explicit Dynamic analysis express the conservation of mass, momentum and energy in Lagrange coordinates. These, together with a material model and a set of initial and boundary conditions, define the complete solution of the problem. For Lagrange formulations, the mesh moves and distorts with the material it models, so conservation of mass is automatically satisfied. The density at any time can be determined from the current volume of the zone and its initial mass:

$$\frac{\rho_0 V_0}{V} = \frac{m}{V}$$

The partial differential equations which express the conservation of momentum relate the acceleration to the stress tensor σ_{ij}:

$$\rho\ddot{x} = b_x + \frac{\partial\sigma_{xx}}{\partial x} + \frac{\partial\sigma_{xy}}{\partial y} + \frac{\partial\sigma_{xz}}{\partial z}$$

$$\rho\ddot{y} = b_y + \frac{\partial\sigma_{yx}}{\partial x} + \frac{\partial\sigma_{yy}}{\partial y} + \frac{\partial\sigma_{yz}}{\partial z}$$

$$\rho\ddot{z} = b_z + \frac{\partial\sigma_{zx}}{\partial x} + \frac{\partial\sigma_{zy}}{\partial y} + \frac{\partial\sigma_{zz}}{\partial z}$$

Conservation of energy is expressed via:

$$\dot{e} = \frac{1}{\rho}\left(\sigma_{xx}\dot{\varepsilon}_{xx} + \sigma_{yy}\dot{\varepsilon}_{yy} + \sigma_{zz}\dot{\varepsilon}_{zz} + 2\sigma_{xy}\dot{\varepsilon}_{xy} + 2\sigma_{yz}\dot{\varepsilon}_{yz} + 2\sigma_{zx}\dot{\varepsilon}_{zx}\right)$$

For each time step, these equations are solved explicitly for each element in the model, based on input values at the end of the previous time step. Only mass and momentum conservation is enforced. However, in well posed explicit simulations, mass, momentum and energy should be conserved. Energy conservation is constantly monitored for feedback on the quality of the solution (as opposed to convergent tolerances in implicit transient dynamics).

Figure 5 shows concrete carbonation process diagram. Concrete is a porous system materials, carbonation of concrete due to CO_2 diffusion through these pores to coagulation internal and reaction with the cement hydration products. Entire diffusion mass transfer process can be summarized as:

- Between the pore water and ambient humidity, temperature and humidity balancing process to form a stable pore water film

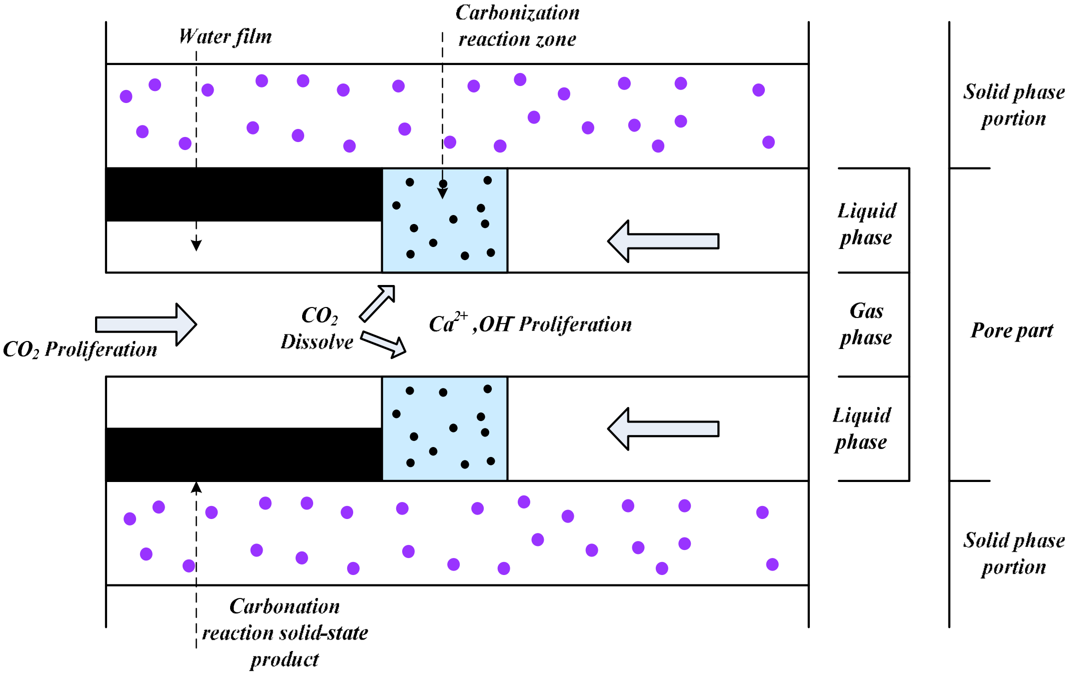


Fig. 5: Concrete carbonation process diagram

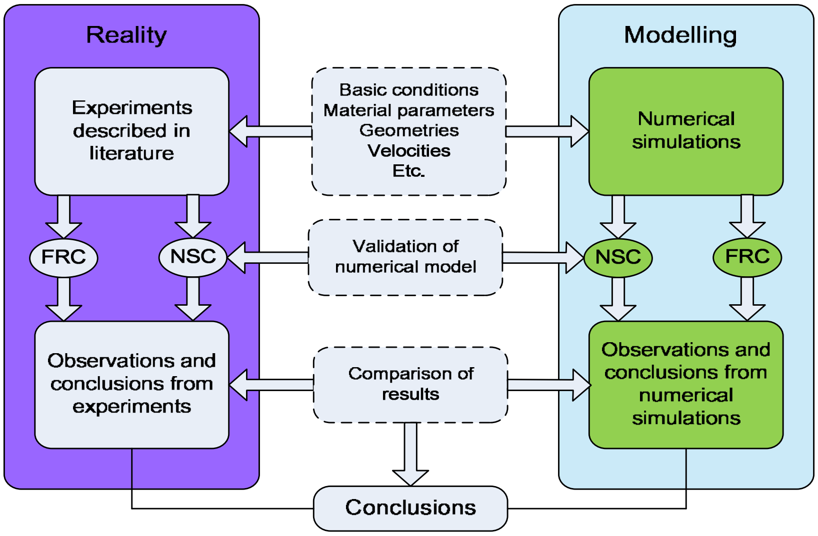


Fig. 6: Schematic illustration of study procedure, where NSC is normal-strength concrete and FRC is fibre-reinforced concrete

- CO_2 gas in the environment through the concrete pores, the gas phase diffusion inside the concrete and dissolved in pore water
- Cement hydration generates the carbonized material hydroxide, calcium Ca $(OH)_2$ and calcium silicate hydrate CSH, the unhydrated C_3S and C_2S also available carbonation substances
- $CaCO_3$, CO_2 (4) was dissolved in water and Ca $(OH)_2$ chemical reaction generates simultaneous CSH C_3S, C_2S also on the solid-liquid interface, the carbonation reaction
- Generated by the carbonation reaction of $CaCO_3$ and other solid substances are clogged in the pores and weaken the subsequent O_2 diffusion

Figure 6 is schematic illustration of study procedure and Fig. 7 shows strain rate range diagram of concrete response under different loads. Due to the wide application of concrete structures to withstand the strain rate range of the load is large, such as the creep strain rate is generally lower than 10^{-6}/s, corresponding structure under seismic loading strain rate of

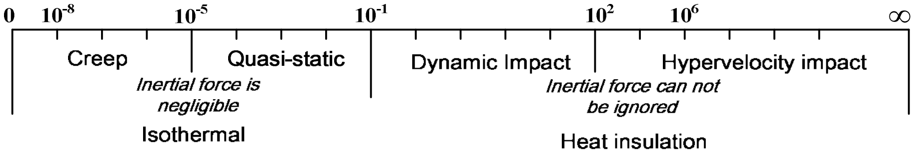


Fig. 7: Strain rate range diagram of concrete response under different loads

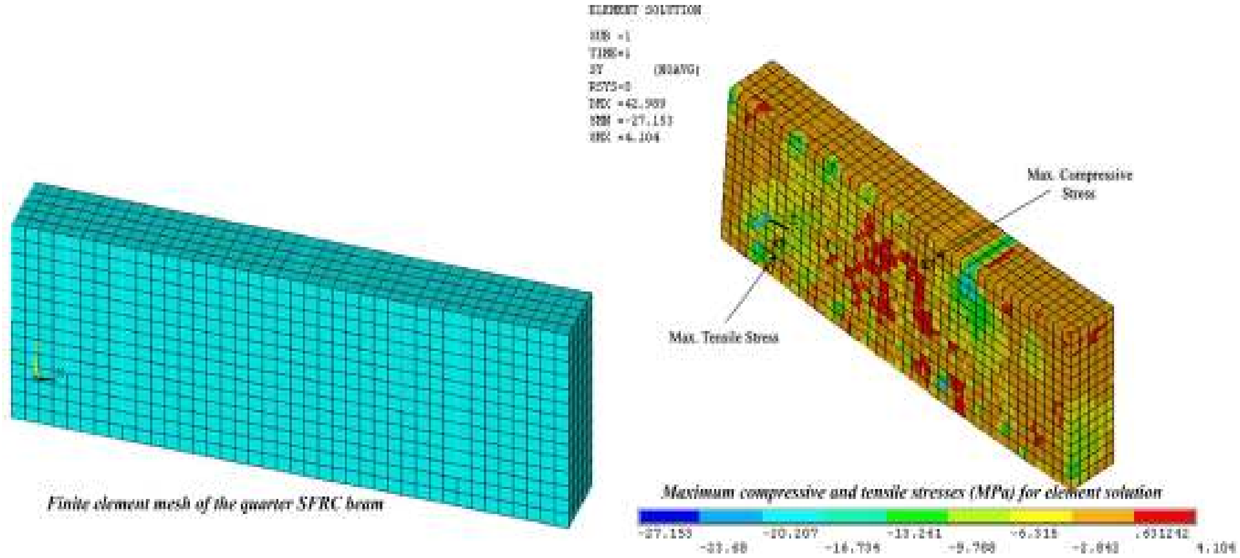


Fig. 8: Finite element study of ANSYS

Table 1: Splitting tensile strength steel fiber reinforced concrete carbonation and acid rain together

				Number of cycles								
				1			2			3		
Specimen group	Factor	Level	Original strength	f_{c+a} MPa	p_{c+a}%	p_a%	f_{c+a} MPa	p_{c+a}%	p_a%	f_{c+a} MPa	p_{c+a}%	p_a%
G	ρ_f	0	6.1	5.4	-11.5	-9.8	5.5	-9.8	-13.1	5.0	-18.0	-21.6
		0.5%	8.1	8.5	4.9	1.2	8.0	-1.2	-6.2	7.3	-9.9	-16.1
		1.0%	9.2	9.7	5.4	-4.3	8.6	-6.5	-7.6	7.8	-15.2	-18.5
		1.5%	11.0	11.9	8.2	5.5	11.0	0	-3.6	10.1	-8.2	-12.6
		2%	7.2	7.1	-1.4	-2.8	6.4	-11.1	-13.9	5.9	-18.1	-19.1

approximately 10^{-3}-10^{-2}/s, impact load of about 10^0-10^1/s under blast loading strain rate reached more than 10^{-2}/s. In the role of the dynamic impact load, a lot of factors that affect the mechanical properties of concrete materials, the main material sensitive to the strain rate effect and the inertia effect, two influencing factors of mutual coupling, it is difficult to complete separation experiments.

The strength measure concrete advantages and disadvantages of important indicators, the indicators are most concerned about the practical engineering of steel fiber reinforced concrete in different test mode Downward Kick pull strength values and the rate of change in the table below. Table p_a acid rain erosion to Downward Kick tensile strength of the rate of change, p_{c+a} specimen carbonation and acid rain are common under splitting tensile strength change rate, $c+a$ specimen carbonation and acid rain under the joint action splitting tensile strength values.

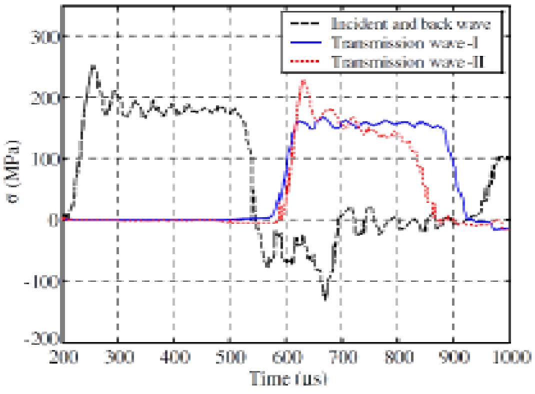


Fig. 9: Recorded waveforms from dynamic compression test

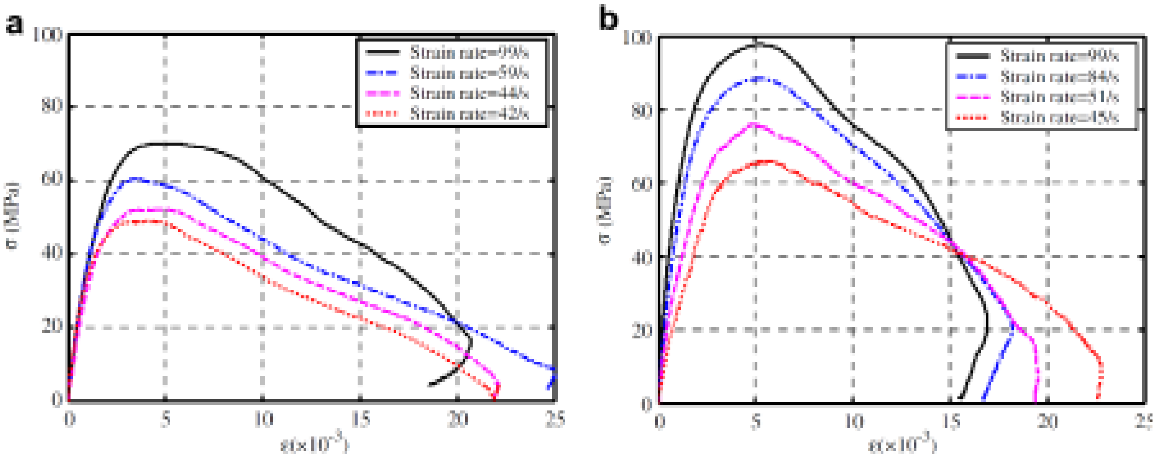


Fig. 10: Dynamic stress-strain curves for SFRC (a) $V_f = 0.0\%$, (b) $V_f = 3.0\%$

In Table 1, Splitting tensile strength steel fiber reinforced concrete carbonation and acid rain together was indicated. In Fig. 8 and 9, finite element study of ANSYS was simulated and waveforms from dynamic compression test were recorded. It should be noted that the impact velocity of the striker influences the destructive degree of SFRC specimen. This can be illustrated where the incident compressive wave was represented by the dashed line. On the other hand, in the case that the specimen was crushed under the dynamic impact of the incident bar, much of the impact energy will be absorbed by the crushed specimen and the impact wave will not be effectively transmitted to the output bar, resulting in a rapidly declining transmission wave as shown by the dotted line labeled as ‘‘transmission wave-II’’.

Figure 10 shows dynamic stress-strain curves for SFRC. The stress-strain relationship of the SFRC specimen can be obtained by analyzing the recorded waves based on one-dimensional elastic bar-wave theory. It is noted that the behavior of the SFRC is significantly sensitive to the strain-rate.

CONCLUSION

With steel fiber reinforced concrete in various engineering fields, including construction, transportation, water conservancy, mining, metallurgy, military, refractory industry gradually promote the application, its durability increasingly attracted attention. General atmosphere of the environment, the neutralization of concrete is the main reason leading to corrosion of steel bars, the resulting loss is immeasurable. Plus environmental issues deteriorating concrete, in which the environment has become increasingly complex, greatly affect the durability of concrete structures. Dutch steel fiber reinforced concrete in erosion environment, the state of bending tensile stress concrete neutral speed greater than the neutral rate of concrete under stress state; concrete bending compressive stress state speed of the basic small neutral concrete neutral rate in the stress-free state. With the increase of the bending tensile stress level, carrying the steel fiber reinforced concrete neutral speed, bearing steel fiber reinforced concrete with the bending compression stress levels increase the speed value of the neutral have a certain degree of reduction. The relationship between the neutral bending stress influence coefficients of the bearing steel fiber concrete stress level can be used to express quadratic polynomial. Consider the impact of steel fiber concrete porosity in ordinary concrete carbonation theoretical model based on steel fiber reinforced concrete carbonation depth forecasting model.

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