Research on Mechanical Properties of HDPE Plastic Fiber Reinforced Concrete Structure

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Abstract

In recent years, with the development of industrial technology, a series of reactions take place between HDPE plastic fibers and related materials to form mixtures for different functions. The crystallinity, melting point, heat resistance and mechanical properties of HDPE plastic fibers change accordingly, and have different effects on highway, housing construction and other areas. As a complex geometric shape, reinforced concrete structure is particular and distinguished from other simple building materials. After mixing the plastic fibers with the reinforced concrete, the crystallinity, heat resistance and mechanical properties of the structure have undergone significant changes. Based on this, this paper analyzes the theories of HDPE plastic fiber reinforced concrete structure, and studies its mechanical properties in detail. It is found that the bending and tensile properties of HDPE plastic fiber reinforced concrete have been improved, but the impact strength decreased. Therefore, prior to construction, the related construction department should select the appropriate HDPE plastic fiber reinforced concrete as raw material according to the nature of buildings so as achieve the goal.

Keywords: HDPE Plastic Fiber, Reinforced Concrete Structure, Mechanical Properties, Research.

1. BACKGROUND

1.1 Introduction

To solve the problem of corrosion of some metal materials in reinforced concrete structures, many scholars at home and abroad have carried out research to replace the ordinary reinforced steel in the market with fiber reinforced plastic (FRP) bars (Wang et al., 2005). In this context, the High-Density Polyethylene (HDPE) composite was injection molded using twin-screw extrusion granulation and its mechanical properties were measured. It was found that HDPE can be used in the manufacture of reinforced concrete structures (Tong et al, 2011). In order to further analyze a series of fracture mechanisms due to damage of HDPE film caused by some construction reasons, the geotechnical centrifuge model and tensile test are induced. It is found that, the damage area of HDPE film type is obviously enlarged under the action of model MSW, non-conducive to the stability of the structure (Xu et al, 2004). Under the action of electron beam irradiation, the HDPE has undergone obvious changes, increasing the compatibility with magnesium hydroxide, the tensile properties and so on (Xu and Liu, 1997). Through the encapsulation of HDPE with this property, the mechanical properties of concrete columns subjected to axial compression were discussed at different angles, and the internal structural stability of concrete was obviously enhanced (Liu et al., 2009). The length of HDPE pipe and the properties of surrounding soil are studied through comparative analysis, which have an adverse effect on the mechanical properties of HDPE pipe structure (Xiao et al., 2017). The mechanical properties of HDPE composite materials with white mud as filler and maleic anhydride grafted polyethylene as a compatibilizer are also enhanced (Xian et al., 2016). The research shows that glass fiber has a slight heterogeneous nucleation effect on high density composites, which makes the elastic modulus of the composites increase, but the impact strength and tensile strength decrease, non-conducive to the forming of hybrid structure (Wang et al., 2016).

1.2 Purpose

The mechanical properties of HDPE were studied. It was found that the addition of EUG to the material increased the heat resistance of the composites and EUG promoted the crystallization of polyethylene (Zhang and Cai, 2007). Based on this, fiber reinforced plastic (FRP) bars have been widely used as a high performance composite material in civil concrete structures, corrosion resistant, oxidation resistant and crush resistant (Xue, 2004). The application of bamboo fiber reinforced plastic in prestressed concrete is analyzed based on the
research results at home and abroad. It is found that the application of bamboo fiber reinforced plastic instead of prestressed concrete beam increases the physical, mechanical and corrosion resistance of the building (Zhang and Cai, 2007). Compared with traditional concrete structures, the research on concrete structures in China is still at primary stage, and the application of related materials started late (Zhang et al., 2004). After a comparative analysis of the physical properties of fiber reinforced plastic (FRP) bars at home and abroad, it is found that there are still problems in the concrete components and fiber reinforced plastic (FRP) bars in our country (Gan et al., 2002). Reinforced concrete structures are used widely in highways, bridges and buildings. Research on alternative materials for reinforcing steel bars has become one of the most urgent problems in current concrete projects (Fu and Wang, 2010). Through the long-term performance testing of the domestic fiber reinforced plastic (FRP) bar concrete beams, it is found that the relaxation of AFRP bars is more obvious than CFRP bars, and the AFRP bars used in engineering will change the structure of concrete beams (Qi et al., 2008). It can be seen that different kinds of plastic fibers have different effects in reinforced concrete structures. Therefore, it is important to study the mechanical properties of HDPE plastic fiber reinforced concrete structure, which is the other branch of plastic fiber composites.

2. THEORY OF HDPE PLASTIC FIBER REINFORCED CONCRETE STRUCTURE

HDPE plastic fiber is also called high-density polyethylene plastic fiber, featuring cold resistance, heat resistance, toughness and rigidity. Compared with the low-density polyethylene fiber, HDPE plastic fiber features good tensile strength and impact strength. At room temperature, HDPE plastic fibers are incompatible with any organic solvent and have good chemical stability. Processes with HDPE plastic fiber reinforced concrete structure as raw material feature the same fast molding and good extrusion and blow molding effect. The HDPE plastic fiber reinforced concrete structure can be used for the production of shutters, composite panels, decorative panels, molded calcium plastic products and synthetic films. The X-ray diffraction property, thermogravimetric property, differential scanning and other properties of HDPE plastic fiber reinforced concrete structures are studied. The X-ray diffraction property of the structure is tested using a diffractometer. The process is: First, Prepare the samples using compression preparation method. Place the samples in the diffractometer for measuring. Second, put the diffractometer at 10-35 during detection as required. Perform reflection of the sample with α-rays of the scanner in reflection mode every five minutes. Finally, the control angle of the device is connected with the copper excitation radiation source. Then emit α-rays using the corresponding device. After all operations are completed, the thickness of the wafer can be calculated by the following formula.

\[
L_{\text{obj}} = \frac{K \lambda}{\beta \cos \theta}
\]

\[
\beta_0^2 = \beta_M^2 - \beta_i^2
\]  (1)

where \( K \) denotes the coefficient related to the thickness of wafer surface, with a certain correlation with the width of the diffracted light. If the width of the diffracted light is a predetermined half-width height, \( K \) is 0.9; \( \lambda \) denotes the set wavelength to measure the sample in nm; \( \beta_0 \) denotes the half-width height of the diffracted light in rad; \( \beta_M \) denotes the reference width of the diffracted light in rad; \( \beta_i \) denotes the reference width of the device in rad.

For the determination of the thermogravimetric property of HDPE plastic fiber reinforced concrete structures, the thermal stability of the composites is studied in related experiments. Put 6-8 mg prepared samples into a thermogravimetric analyzer. Under protection by nitrogen, the temperature was raised to about 650°C at a constant rate. Measure three sets of samples and record.

The differential scanning calorimetry test of HDPE plastic fiber reinforced concrete structure is mainly based on the principle of differential scanning calorimetry, so as to measure and analyze the crystallization behavior of HDPE materials. Put 6-8 mg prepared samples into a differential scanner. The temperature was raised to 160°C at a rate of 10°C per minute. Maintain the temperature and handle for a certain period of time. The temperature restores to the original one at a rate of 10°C per minute. After the operation is completed, the crystallinity of the sample can be calculated by the following formula.
\[ X_t = \frac{\Delta H_{\text{exp}}}{\Delta H} \times \frac{1}{W_t} \times 100\% \]  

(2)

where \( \Delta H \) denotes the calorific value of HDPE melt crystallization in ideal state; \( \Delta H_{\text{exp}} \) denotes the calorific value of melt crystallization of the measured composites; \( W_t \) denotes the mass fraction of HDPE in the material. Three samples shall be tested in the differential scanning calorimetry test in order to ensure data stability and consistency.

According to the measurements and the formula, the results of properties of HDPE plastic fiber reinforced concrete structure can be obtained. The X-ray diffraction property, thermal stability and crystallinity of this structure are good. In general, the mechanical properties of HDPE plastic fiber reinforced concrete structures are studied in practice.

3. MECHANICAL PROPERTIES OF HDPE PLASTIC FIBER REINFORCED CONCRETE STRUCTURE

Different change to the shape and size of HDPE plastic fiber reinforced concrete structure will occur under external force, generally referred to as deformation. The deformation can be expressed as

\[
\sigma = \frac{F}{A_0}: \quad S = \frac{F}{A}: \quad \varepsilon = \sigma (1 + \varepsilon)
\]

(3)

where the stress component is \( \sigma_{xx}, \sigma_{yy}, \sigma_{zz}, T_{xy}, T_{yz}, T_{zx} \)

\[
\varepsilon = \frac{\Delta L}{L_0}; \quad e = \int \frac{dL}{L} = \ln \frac{L}{L_0}
\]

\[
\varepsilon_{xx} \varepsilon_{yy} \varepsilon_{zz} \gamma_{xy} \gamma_{yz} \gamma_{zx}
\]

(4)

Some materials can restore within a certain period of time after deformation. However, HDPE plastic fiber reinforced concrete structures is difficult to recover within a certain period after deformation under external force, easy to cause permanent deformation, not only affecting the appearance of the structure, but also having some dangers. The study of the mechanical properties of HDPE plastic fiber reinforced concrete structures includes three steps: material selection and preparation, mechanical properties determination and result analysis.

3.1 Material selection and preparation

Take some HDPE plastic fiber reinforced concrete composites with a proper instrument, and then place in a desiccator. Dry for 24h under 95°C. After drying, grind with model 3383L10 grinder to 20 mesh. Put in a ziplock bag. Mix all materials by a high shear mixer. Stop mixing after the temperature reaches about 190°C. Cool the mixed materials in the air. When the mixed material is solidified, pulverize the material using a granulator. Stop pulverizing when the particles are about 1 cm. Take out the materials for future use. Finally, put the materials into the hopper of injection molding machine for injection molding. Stop after injection molding to the required shape for the experiment. The equipment used in this experiment is selected according to the actual situation. Adjust based on the actual experimental material if necessary. All operations must meet the national standard requirements.

3.1 Testing mechanical properties of HDPE plastic fiber reinforced concrete structure

For the determination of the mechanical properties of HDPE plastic fiber reinforced concrete structures, a universal mechanical testing machine was used to determine the bending property, tensile property and impact strength of the prepared materials according to the corresponding standards. 3 sets of data are required for the determination. 4 samples retain in each set of data so as to improve the accuracy of the experiment and ensure the stability and consistency of the measurements.
The bending property means the bending of HDPE plastic fiber reinforced concrete structure (Figure 1).

![Figure 1](image)

**Figure 1. Bending of HDPE plastic fiber reinforced concrete structure**

As can be seen from Figure 1, the bending property determines the plasticity of the structure. If the plasticity of the structure is good, it is less likely that the structure will delaminate and fracture. The tensile property of HDPE plastic fiber reinforced concrete structure is also called elongation, mainly calculated by the following formula.

\[
\delta = \frac{l_1 - l_0}{l_0} \times 100\% \\
\begin{cases} 
\delta_3 & l_1 = 5d \\
\delta_{10} & l_1 = 10d
\end{cases}
\]

(5)

Where \( \delta \) denotes the diameter of HDPE plastic fiber reinforced concrete structure. The value 5 times or 10 times of the diameter is taken for calculation in general. \( l \) denotes the length of HDPE plastic fiber reinforced concrete structure. The impact resistance of HDPE plastic fiber reinforced concrete structure is mainly indicated by the notched impact strength of the structure. When the impact strength is high, the HDPE plastic fiber reinforced concrete structure has certain impact resistance and good structural stability.

### 3.3 Analysis of results

According to the above formula and related requirements, the measurements of mechanical properties of HDPE plastic fiber reinforced concrete structure are shown in Table 1.

According to Table 1, the bending modulus and bending strength of HDPE plastic fiber reinforced concrete structures are both 55% and 51% higher than that of pure HDPE plastic fibers. The impact of HDPE plastic fiber reinforced concrete structure obviously declines. The reason is mainly that, the tensile fibers remain in the HDPE plastic fiber matrix during processing of HDPE plastic fiber reinforced concrete structure due to some reasons, although the rigidness of the structure is improved, but lead to the decline of its toughness. In general, the bending and tensile property of HDPE plastic fiber reinforced concrete structures have been improved, but the impact strength decreased.

<table>
<thead>
<tr>
<th>Number</th>
<th>Bending Property</th>
<th>Tensile Property</th>
<th>Impact</th>
</tr>
</thead>
</table>

**Table 1** Measurements of mechanical properties of HDPE plastic fiber reinforced concrete structure
<table>
<thead>
<tr>
<th>sample</th>
<th>Bending Modulus (GPa)</th>
<th>Bending Strength (MPa)</th>
<th>Tensile Modulus (GPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Tensile Elongation (%)</th>
<th>Notched Impact Strength (KJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>0.95(0.07)</td>
<td>25.57(0.82)</td>
<td>1.32(0.10)</td>
<td>24.30(0.33)</td>
<td>10.28(0.39)</td>
<td>26.33(1.17)</td>
</tr>
<tr>
<td>control</td>
<td>1.48(0.15)</td>
<td>38.66(3.30)</td>
<td>1.68(0.16)</td>
<td>25.40(1.44)</td>
<td>10.04(0.93)</td>
<td>6.22(0.27)</td>
</tr>
<tr>
<td>D1</td>
<td>1.25(0.05)</td>
<td>35.77(0.87)</td>
<td>1.75(0.15)</td>
<td>26.91(0.40)</td>
<td>10.07(0.53)</td>
<td>3.86(0.29)</td>
</tr>
<tr>
<td>D2</td>
<td>1.16(0.05)</td>
<td>32.25(0.80)</td>
<td>1.70(0.11)</td>
<td>28.27(0.49)</td>
<td>12.87(0.37)</td>
<td>7.98(0.72)</td>
</tr>
<tr>
<td>D3</td>
<td>1.18(0.03)</td>
<td>35.56(0.38)</td>
<td>1.76(0.08)</td>
<td>27.43(0.50)</td>
<td>10.95(0.36)</td>
<td>10.43(0.35)</td>
</tr>
<tr>
<td>D4</td>
<td>1.02(0.03)</td>
<td>36.38(0.30)</td>
<td>1.54(0.02)</td>
<td>25.95(0.14)</td>
<td>11.68(0.43)</td>
<td>11.60(0.18)</td>
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<tr>
<td>P1</td>
<td>1.38(0.06)</td>
<td>37.40(0.79)</td>
<td>1.71(0.14)</td>
<td>28.04(0.51)</td>
<td>11.41(0.71)</td>
<td>4.27(0.97)</td>
</tr>
<tr>
<td>P2</td>
<td>1.23(0.06)</td>
<td>39.59(0.87)</td>
<td>1.70(0.11)</td>
<td>28.27(0.40)</td>
<td>12.87(0.35)</td>
<td>7.98(0.72)</td>
</tr>
<tr>
<td>P3</td>
<td>1.19(0.03)</td>
<td>35.56(0.40)</td>
<td>1.72(0.05)</td>
<td>27.65(0.39)</td>
<td>11.92(0.41)</td>
<td>10.72(0.20)</td>
</tr>
<tr>
<td>P4</td>
<td>1.21(0.01)</td>
<td>36.40(0.30)</td>
<td>1.67(0.02)</td>
<td>27.00(0.46)</td>
<td>11.57(0.39)</td>
<td>13.56(0.65)</td>
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<tr>
<td>N1</td>
<td>1.22(0.07)</td>
<td>37.40(0.79)</td>
<td>1.74(0.06)</td>
<td>26.66(0.58)</td>
<td>9.62(0.14)</td>
<td>5.68(0.90)</td>
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<tr>
<td>N2</td>
<td>1.20(0.05)</td>
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<td>1.71(0.06)</td>
<td>26.90(0.42)</td>
<td>9.64(0.23)</td>
<td>11.44(0.83)</td>
</tr>
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<td>N3</td>
<td>1.25(0.04)</td>
<td>39.80(0.97)</td>
<td>1.72(0.08)</td>
<td>27.66(0.21)</td>
<td>9.55(0.28)</td>
<td>22.97(2.43)</td>
</tr>
<tr>
<td>N4</td>
<td>1.21(0.02)</td>
<td>37.50(0.41)</td>
<td>1.79(0.06)</td>
<td>27.56(0.22)</td>
<td>9.56(0.23)</td>
<td>30.18(1.93)</td>
</tr>
</tbody>
</table>

4. BRIEF CONCLUSION

In summary, by analyzing the theory and studying the mechanical property of HDPE plastic fiber reinforced concrete structure, it is found that compared with pure HDPE plastic fiber, the bending modulus and the bending strength increase by 55% and 51% respectively, but the impact strength decreases gradually. This HDPE plastic fiber reinforced concrete structure is suitable for buildings requiring materials with high bending and tensile properties, which greatly improves the tensile strength of buildings. Thus the HDPE plastic Fiber reinforced concrete structures have great prospects. I believe in the near future, HDPE plastic fiber reinforced concrete structures will be widely used in the field of construction.

REFERENCE
