Research on Waste FRP Fiber Reinforced Adhesive Mortar

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Abstract. The use of FRP in industry results in large amount of waste FRP. If not treated properly, it will pollute the environment. In our study, waste FRP powder was used in mortar to substitute part of sand in mortar. The use of short waste FRP fibre can further increase the mechanical strength. The Waste FRP fibre reinforced adhesive mortar was prepared with the material proportioning: cement-sand ratio 1:2, polymer 8% (cement based), waste FRP fibre 3% (based on the total solids). The performance of the mortar conforms to JCT 547-2005 with excellent adhesive characteristics.

1. Introduction

Glass fiber reinforced plastic (GFRP) is a kind of light and high strength material, which is widely used in various fields of life. In 2013, the total production of GFRP reached 4 million tons, in which thermosetting (FRP) was 2.73 million tons and thermoplastic glass steel (FRTP) was 1.37 million tons. Waste glass fiber reinforced plastic has some characteristics such as high strength and strong corrosion resistance, which make it difficult for recycling and utilization. Recycling and utilization of waste glass fiber is becoming an important factor hindering the development of glass fiber industry [1-2]. How to deal with the wasted glass fiber has become a pressing issue in glass fiber industry in China and in the world.

The research on the recycling of waste glass fiber reinforced plastics is still in the primary stage, mostly going for incineration and landfill in practice. Both will pollute the environment, have high processing cost and cannot meet the increasing requirements of processing the wasted glass fiber [3-4]. According to the present recycling methods of GFRP waste materials, it can be divided into physical recycling, chemical recycling and energy recovery [5-6]. Among the three methods, physical recycling is the most used because of operatability and cost-effectiveness. Xiaosong et al. [7] treated waste powder GFRP material with organic surface treatment, and effectively improved the interfacial adhesion with the matrix resin to improve the mechanical properties of the prepared composites. The properties of waste powder FRP make it possible substitute of sand in mortars [8-9]. Shaojie et al. [10] studied that the core-shell emulsion polymerization styrene-acrylonitrile polymer prepared by P (St-DVB-HEMA) can be used for adhesive mortar. Results showed that the core-shell cross-linked poly (styrene-hydroxyethyl methacrylate) could substantially improve the modified-mortar’s bond strength compared to the mortar with commercial EVA as modifier.

The purpose of this paper is to formulate a waste FRP fiber reinforced adhesive mortar on the basis of selecting polymers, cement-sand ratio and different size of waste FRP fiber. Another purpose is to find a proper method to utilize waste FRP.
2. Materials and methods

2.1. Materials

Cement-sand ratio, fineness modulus of 2.5; Portland cement: P. 42.5. The physical properties are listed in Table 1. Fibers: waste glass fiber reinforced plastic fiber (WGFP), size 1~3 mm, supplied by Jizhou Hebei Machinery Equipment Technology Co., Ltd (Figure 1). Polymers: EVA powder (ethylene vinyl acetate copolymer), VAE emulsion (ethylene vinyl acetate copolymer emulsion), styrene butadiene latex, styrene acrylic emulsion, rubber latex. Water retaining agent: hydroxypropyl methyl cellulose ether.

| Specific surface area of cement (m²/kg) | Normal Consistency (%) | Setting time (min) | Compressive strength (MPa) | Bending strength (MPa) | Stability (boiling method) |
|----------------------------------------|------------------------|--------------------|---------------------------|----------------------|--------------------------|
|                                        |                        | Initial setting    | Final setting             | 3d                   | 28 d                     | 3d | 28 d |                        | Qualified |
|                                        |                        | 370                | 26.2                      | 164                  | 252                      | 32.4 | 57.7 | 6.7                   | 8.28       |

Figure 1. WGFP fiber with different sizes (by mechanical crushing).

2.2. Methods

For preparation and testing of the samples. Portland cement, sand, Waste FRP fiber, re-dispersible emulsion and additives are mixed to form adhesive mortar, which is then mixed with water to make the test specimens (40 mm × 40 mm × 10 mm). The specimens are cured in the mold for 24 h, then keep in 23 (± 2) °C temperature & 50 (± 5) % relative humidity (RH) for the 27 days. The adhesive strength is tested according to JCT 547-2005 (China professional standard, adhesives for ceramic wall and floor tile). All the values collected were the average of six separate tests. SEM test was done using HITACHI S-570 Scanning Electron Microscope.

3. Results and discussion

3.1. Orthogonal experiment

On the basis of initial tests, VAE emulsion was selected for modification of mortar with the proper content of 8 % (based on the cement mass). The water retaining agent used is hydroxypropyl methyl cellulose ether with the content 0.2% (based on the total solids). Three factors and three levels, the
amount of cement sand ratio (A), polymer content (B) and waste FRP fiber (C) were selected for orthogonal experiment to determine the optimal proportioning of mortar. See Table 2.

| Table 2. Factors and levels. |
|-----------------------------|
| Factor | A (Cement-sand ratio) | B (Polymer content) | C (Short fiber content) |
|-------|------------------------|----------------------|------------------------|
| Level 1 | 1:2 | 4% | 1% |
| Level 2 | 1:2.5 | 6% | 2% |
| Level 3 | 1:3 | 8% | 3% |

3.2. Result analysis

The response data collected from the experiments were listed in Table 3.

| Table 3. Range analysis. |
|--------------------------|
| Number | 1 | 2 | 3 | Bonding strength (MPa) |
|-------|---|---|---|-------------------------|
| 1 | 1 | 1 | 1 | 1.09 |
| 2 | 1 | 2 | 2 | 1.04 |
| 3 | 1 | 3 | 3 | 1.15 |
| 4 | 2 | 1 | 2 | 0.98 |
| 5 | 2 | 2 | 3 | 1.01 |
| 6 | 2 | 3 | 1 | 1.05 |
| 7 | 3 | 1 | 3 | 0.9 |
| 8 | 3 | 2 | 1 | 0.88 |
| 9 | 3 | 3 | 2 | 0.96 |
| Range | 0.180 | 0.076 | 0.023 |

With the bonding strength of the samples as objective, the effects of VAE emulsion, cement-sand ratio and waste FRP fiber contents were studied. The range analysis of the results was performed. The influence order of the factor is: A>B>C. Among the three factors, cement-sand ratio shows the most remarkable impact.
Figure 2 gives factor-effect diagram of the experiment. With bonding strength value of the samples as objective, then the optimal combination of adhesive mortar is A1B3C3, that is to say, when the cement-sand ratio is 1:2, the polymer is 8% (cement based), and waste FRP fiber is 3% (based on the total solids).

3.3. Verification test

Based on the orthogonal experiment, the obtained optimal combination of factors and levels are A1B3C3. The verification test was performed. The bonding strength values of the mortar with the optimal combination is 1.19MPa. The product conforms to JCT 547-2005.

3.4. Microstructure of waste FRP fiber reinforced adhesive mortar

Figure 3 (a) and (b) show the SEM photos of the waste FRP fiber reinforced adhesive mortar (with and without polymer modification). Just as reinforced concrete, the needle-like fiber strengthens the structure. Cement paste wrapped around, and uniformly dispersed in the mortar and matrix interface, which increases the bonding strength. The polymer further improves the bonding of cement mortar as well as bonding with latex. In this case, cement paste and aggregate is connected closely, so that mortar adhesive properties are improved. It also shows that the adhesive properties of modified mortars are greatly influenced by VAE latex. Waste FRP fiber are evenly scattered in cement composite system so that adhesive strength of hardened cement composites is significantly improved. At the same time, the stress concentration on crack tip is effective alleviated, which offers great help to the performance of adhesive strength.

(a) Mortar with polymer emulsion       ( b) Mortar without polymer emulsion

Figure 3. SEM photos of FRP fiber reinforced adhesive mortar.
4. Conclusions

- Waste FRP fiber can be used in functional mortar with enhanced adhesion properties. The results show that the moderate content of fiber powder can greatly improve the adhesive strength.

- Different kinds of polymer were used to modify mortar; VAE emulsion exhibits excellent properties when used in the formulation. When the content of VAE emulsion is 8%, the bonding strength is better.

- Based on three factors & three levels orthogonal experiment, the Waste GFRP fiber reinforced adhesive mortar was prepared with the material proportioning: cement-sand ratio 1:2, polymer 8% (cement based), waste FRP fiber 3% (based on the total solids). The performance of the mortar conforms to JCT 547-2005 with excellent adhesive characteristics.

- The mechanism of adhesive strength improvement of waste FRP fiber reinforced mortar was investigated by using SEM. Waste FRP fiber, and VAE emulsion penetrated each other, forming dense system, which increased the bonding strength of the mortar.

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