Project Title:	Development of Ultra-Ductile Cementitious Waterproofing Rendering by using Recycled Plastic
Principal Investigator:	Dr. Ivan M. L. SHAM
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Research Institution:	Nano and Advanced Materials Limited
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Objective

To develop an ultra-ductile cementitious rendering for waterproofing application, using recycled polyethylene terephthalate (PET) fibers made from waste bottles.

Background

Water seepage is a common problem in reinforced concrete structures. Applying waterproof coating to prevent water seepage is the most common mitigation measure. Typically cement-based waterproof rendering is used but it is brittle and can crack easily due to crack propagation in the concrete substrate or differential displacement at the joint. Epoxy based waterproof coating is also used. The volatile organic compound level inside is high and can also crack due to its brittleness. The high-end waterproof product, such as polyurea/polyurethane based waterproof coating, has excellent tensile strength and ductility, but it cannot be applied on wet surface. Hence, the application of such waterproof coating is limited by weather and the conditions of concrete surface.

An ultra-ductile Engineered Cementitious Composites (ECC) as waterproofing by employing PVA has been developed for decades but the high cost of PVA fibers limits the wide applications of ECC in civil engineering. If the ultra-ductile ECC can be produced from recycled plastic bottles, it would reduce the cost of producing ECC and lead to wider applications.

Methodology

- The collected waste plastic bottles, which were made of PET, were crushed into small pieces. The crushed PET was melt and extruded into continuous filament.
- Falling head tests were performed to determine the permeability of the material.
- Tensile tests were carried out on the proposed ultra-ductile cementitious rendering. To prevent crushing at the gripped region in the testing machine, the specimen was protected by carbon fibre reinforced polymer sandwiched by two aluminum plates. The displacement was measured by two linear variable differential transformers (LVDTs) at two sides.
- Pull-off tests were carried out to assess adhesion strength between ECC and concrete substrate in tension in accordance with ASTM D7234-12 (2012). 50 mm diameter dolly was attached on ECC by epoxy. Four failure modes were identified.
- The flow table test in accordance with BS EN 1015-3 was conducted to evaluate the consistency of rendering.

Results and Findings

Water Permeability

The coefficient of water permeability of the ECC rendering was measured to be 4.46×10^{-10} cm/s.

Physical Properties of Various Fibers

Physical properties of PVA and PET fibers (lab test)						
Fiber	**Length (mm)**	**Diameter (μm)**	**Aspect ratio**	**Modulus of elasticity (GPa)**	**Fiber strength (MPa)**	**Density (g/cm³)**
PVA	12	39	308	16.9	1275	1.30
PET	12	38	318	10.7	1095	1.37

Pull-out test was performed on plain PET, treated PET fiber and PVA fiber to determine the bond strength of various fibers with cementitious matrix. The results indicated that after treatment the bond strength was slightly increased.

Mechanical Properties of Cementitious Rendering

Compression test: Based on the results, all the mixtures achieved the compressive strength of 30 MPa or higher at 28-day age, and 48 MPa or higher after accelerated aging curing.

Uniaxial tensile test: ECC with pure PVA fibers showed the best performance in terms of tensile strength and ductility for both standard 28-day curing and accelerated curing. The hybridized samples treated with PET fibers showed higher strength and improved ductility over those with untreated PET fibers. These results indicated that the fiber surface treatment was effective in enhancing the alkali resistance of recycled PET fibers.

Crack width analysis: Specimens with treated fibers have generated better control on the average crack width than the untreated fibers. For example, one of the results showed that the average crack width was under 100 μm at 1.0%, and the maximum crack width was under 150 μm at 0.625% under standard 28-day curing condition.

Four-point bending test: Multiple cracking was observed in all the samples, and similar first cracking strength was recorded. The ECC with pure PVA fibers showed the best performance in terms of both bending strength and bending ductility. From the test results, it was observed that even when 50% of PVA fibers were replaced by recycled PET fibers, the bending ductility was around 2.50×10^{-3}/cm, which was only 25% less than the ECC with pure PVA fibers.

Workability Tests of Cementitious Rendering

Pull-off tests: Results are shown in the table below. The results indicate that for long-term performance, PVA should be added.

Flow table test: If the w/b ratio is lower than 0.28, fiber could not mix well in mortar. 1.5% PVA could help achieve the right consistency of ECC. Based on the results, it is suggested to use the w/b ratio of 0.28 and 1.5% PVA.

Bending flexibility test: Four 150mm x 400mm x 50 mm concrete specimens were tested. It is found that the peak load of the sample coated with 15 mm thick ECC and 1 mm thick top coat is10 kN, and the ultimate deflection is up to 2mm. In contrast, the peak load and ultimate deflection of the beam coated with conventional 15mm thick cement-sand mortar without fiber are 5.5 kN and 0.5mm, respectively.

Adhesion strength between ECC and substrate under different condition

Test (3 specimen)	Testing condition	Adhesion strength (MPa)		Failure mode
		Ave.	Std.	
1. Control	7 day curing	0.853	0.039	At the ECC-substrate interface
2. Dry surface		0.306	0.054	
3. With commercial top coat		0.833	0.09	
4. With 1.5% PVA		0.463	0.062	Failure in the ECC
5. Control	28 day curing	0.865	0.005	At the ECC-substrate interface
6. With 1.5% PVA		1.23	0.12	

* In the first case Control, samples were prepared on wet substrate surface and subject to standard curing for 7 dates.

Recommendations

- Proper material preparation and mix method for large scale production – Dry powder materials and fiber should be pre-mixed before adding water. A proper mixing machine should be used to uniformly mix and disperse the fibers.
- Preparation of the concrete substrate – In order to achieve the expected performance of rendering, the concrete substrate should be chiseled by mechanically roughening or high pressure water-jet.
- Optimum flowability of rendering for straight wall application – The flowability of rendering could be adjusted according to circumstances.
- Durability of rendering – Durability tests should be carried out to estimate the service life of the rendering.
- Waterproofness - To deal with different levels of water seepage, integration of fast setting material and polymeric membrane to form a waterproofing system is recommended.