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Research & Application of the Cracking Resistance Test Method of Base-Coat & Render

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Abstract: The cracking resistance of base-coat & render are important for ETICS. The current cracking resistance test method can not correctly characterize the cracking resistance of base-coat & render. The suitability of the self-developed test method for cracking resistance and the existing methods was studied and compared. The results show: the value of the ultra flexural-displacement by the new test method is more suitable for representing the cracking resistance performance than the impact resistance, the ratio of compressive/flexural strength, the tensile strength, the transverse deformation. The new test method developed by ourselves can directly compared the correlation between mesh specimens and non-mesh specimens, accurately test the effect of fiberglass mesh in the render. The value of the ultra flexural-displacement of base-coat is nearly linear positive correlation with the amount of the VAE emulsion powder in the base-coat. The fiberglass mesh is important for the render cracking resistance. The position of the mesh in the render can significantly influence the render cracking resistance. As the sample with mesh in fixed position, whether cracking is mainly depend on the base-coat, whereas whether breaking is mainly depend on the mesh. The research results have provided a direct basis for the establishment of relevant standards; should be helpful to solve the industry problem that the surface of ETICS engineering is easy to crack.

Keywords: Cracking Resistance, Test Method, Base-Coat, Render, Research, Application

1. Introduction

External thermal insulation composite system (ETICS) is the most representative type of building thermal insulation with excellent comprehensive performance, its structure generally includes: indoor-wall-bonding mortar-insulation board-render (base-coat with glass fiber mesh) -finish coat-outdoor [1, 2].

One of the main performance of ETICS is that cracking shall not occur for either the render or the ETICS. As the reinforced base coat provides most of the mechanical properties of the render, the anti-cracking performances of the base coat without and with reinforcement (normally reinforced with mesh) are very important [2-6].

For cementitious base-coat, the ratio of compressive strength to flexural strength (C/F $\leq$ 3.0) is used to represent the anti-cracking performance of the base-coat without reinforcement in related standards [7-10] and literature [11-17]. However, our experiments showed that the result of the weather resistance test of ETICS had been unsuccessful when the polymer content in the base-coat was not enough although C/F was < 3.0 [3].

The performance of impact resistance is also used to represent the anti-cracking performance of the render (base-coat with reinforcement) in related standards [7-10]. However, the quality and position of the glass fiber mesh in the base-coat should greatly influence the impact resistance test results, and the relevant standards [7-10] do not clearly specify them. And, according to the molding method of impact-resistant specimens in relevant standards, the position of the glass fiber mesh is difficult to be accurately controlled. In addition, in the evaluation of the impact resistance test results, the length and width of the crack are not clearly specified, and whether there are any crack with the naked eye is not rigorous. Therefore, the test results of different laboratories and different test personnel differ greatly.

Li Bing et al. [18] briefly described the factors resulting in the render cracking: self-shrinking, humidity deformation and temperature deformation of the base-coat. They believe that the moisture deformation is negligible, that is, the cracking resistance of the base-coat mainly depends on the self-shrinkage and temperature deformation. The cracking resistance of base-coat is expressed as the cracking strain (characteristic crack width $W_{rk)}$ and tested according to the method of ETAG 004 [19].

In ETAG 004 [19], (1) for base-coat without reinforcement, the sample measuring 3mm*50mm*300mm is subjected to a tensile test using a suitable machine which records the tensile stress and elongation; (2) for render (base-coat with reinforcement), the characteristic crack width W_{rk} at completed cracking shall be given in the ETA for the warp and weft direction with reference to the render strip (measuring dr*100mm*600mm, dr = thickness of the base coat with embedded reinforcement) tensile test; (3) for ETICS, requirements such as no cracking and qualified impact resistance after weather resistance test are put forward. However, the area of the weather resistance test specimen is too large (≥6m^2), the specimen is not easy to make, so it is difficult to do a large number of regular studies, and the weather resistance test cannot be used for routine test. When the axial tensile strength of the 3mm*50mm*300mm base-coat specimen is tested, the flatness of the specimen is difficult to match with the metal claw, and the tightening force of the claw is difficult to control manually, which makes the test results more discrete. For the detection of 600mm*100mm*dr render specimen containing glass fiber mesh, ETAG 004 does not define the position of the mesh (but the position of the glass fiber mesh is very important), which greatly reduces the significance of the test method and results.

Hadi Haeri et al. [20] used the ratio of compressive strength to tensile strength to characterize the fracture toughness of mortar. There are still problems similar to ETAG 004 method although some progress has been made.

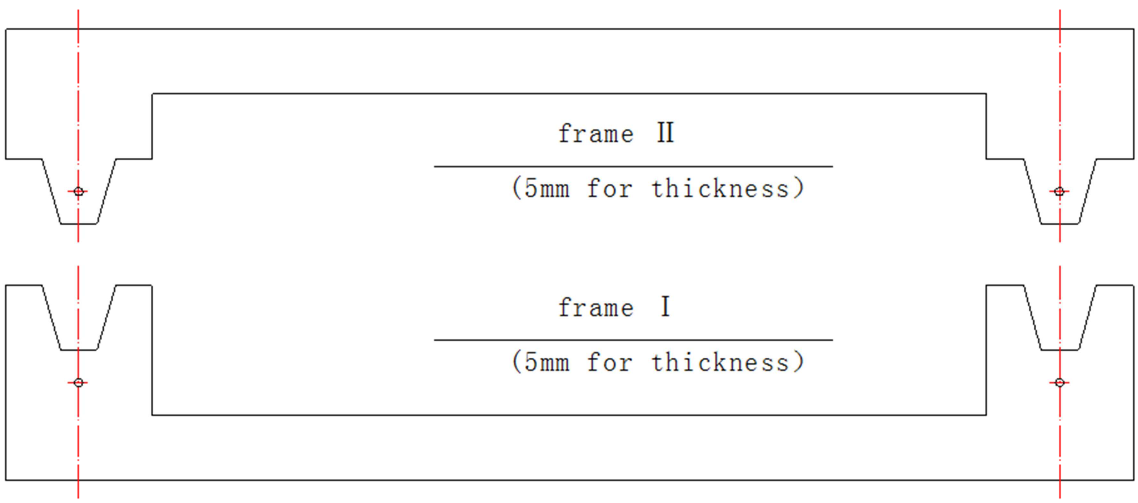
Ru Wang et al. [21] used transverse deformation to characterize the flexibility of polymer-modified cement mortar, their test method is closer to the reality, and the test process is not affected by metal claws. Wang Ru et al. [22] compared the transverse deformation and C/F: both of them can characterize the toughness of styrene acrylic emulsion cement mortar, but their sensitivity is different in different toughness ranges. The transverse deformation increases linearly with the increase of toughness, and the sensitivity remains unchanged in the test range. On the other hand, C/F is curvilinear, and its sensitivity decreases when the toughness is larger. Wang Ru et al. [23] also found that the lateral deformation of butadiene emulsion modified cement mortar is the most sensitive when the toughness is high, and its C/F is more sensitive when the toughness is low, while its impact resistance is more sensitive throughout the test range. However, transverse deformation specimens are difficult to make [24]. Moreover, glass fiber mesh cannot be added to the specimen, which is still far from the actual situation of ETICS.

The above problems have plagued the industry for many years, seriously hindered the development of the external wall insulation industry.

2. New Cracking Resistance Test Method and Supporting Equipment

2.1. Mould

The self-designed mould includes frame I (one piece), frame II (1 piece), frame III (1 piece), frame IV (1 piece), strips (2 pieces) and steel rulers (2 pieces). The detail drawing of the mould is shown in Figure 1, and the assembly drawing is shown in Figure 2.



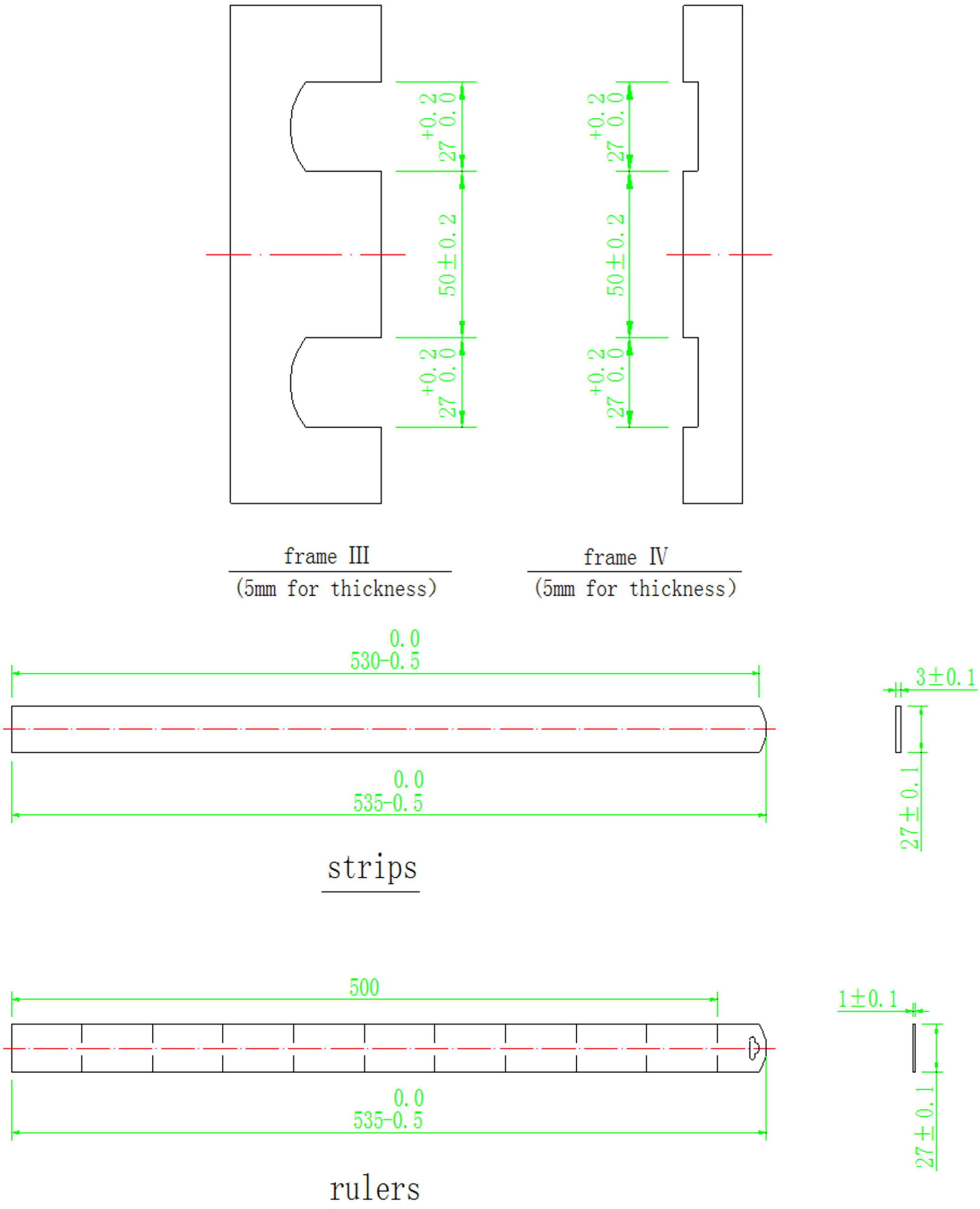


Figure 1. *Detail drawing of the mould.*

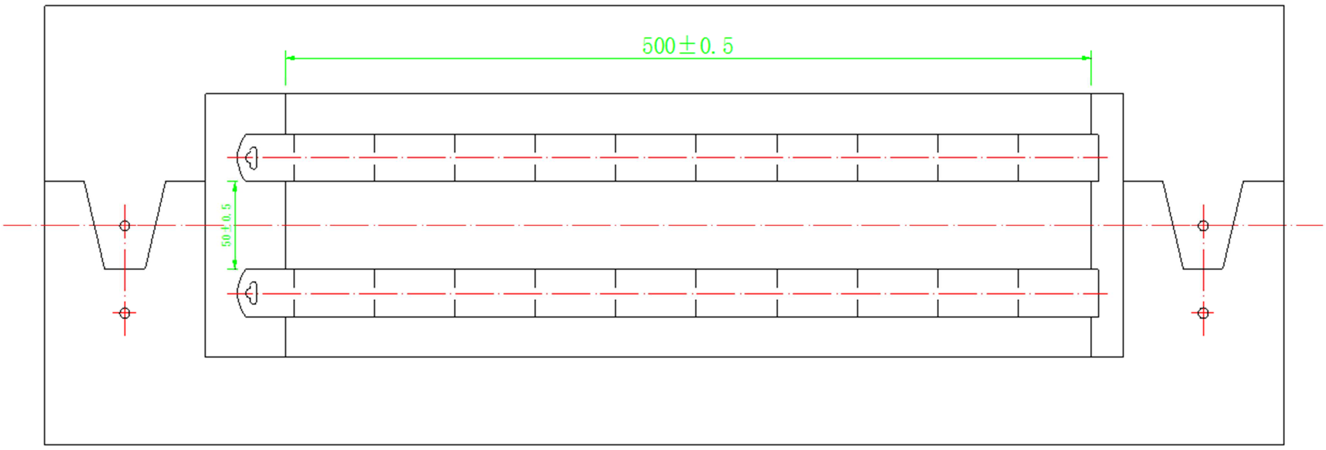


Figure 2. *Assembly drawing of the mould.*

2.2. Machine for Anti-Cracking Test

Figure 3 is a schematic diagram of a new three-point flexural tensile cracking resistance test developed by ourselves, which includes a universal test and a self-made fixture.

The universal test is UTM6503 with a computer.

The diameter of the stainless steel horizontal central axis is Φ25±0.1mm with ≥ 50 mm net widths. The diameter of the stainless steel horizontal end shaft is Φ10±0.1mm with ≥ 50mm net long and 350mm center spacing. The other details could be found in JC/T 2559-2020 [25].

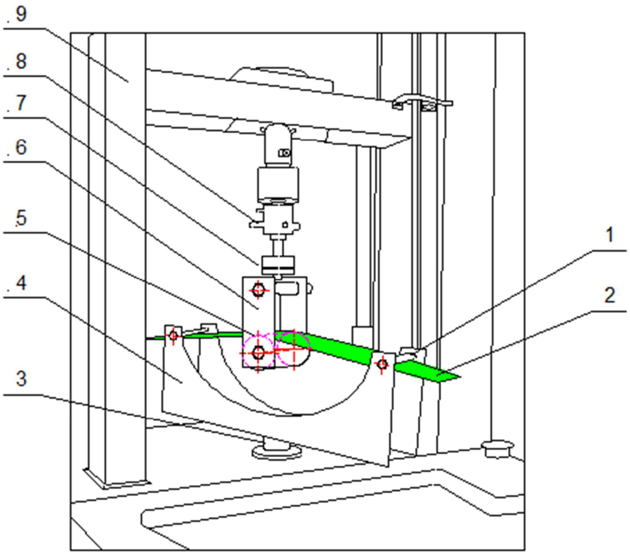


Figure 3. *Schematic diagram of three-point flexural tensile cracking resistance test machine.*

Explain:
1. Horizontal end shaft;
2. Specimen;
3. Connector;
4. U support;
5. Horizontal central axis;
6. Connecting piece;
7. Universal joint;
8. Stretching head;
9. Universal test machine

2.3. Test Method

2.3.1. Assembling of Mould

A piece of PE thin film is flatted and fixed to the surface of a horizontal glass panel.

According to Figure 2, the mould is assembled on the PE film: the frame III and frame IV are placed in the frame I, then two strips are placed on the PE film between the frame III and frame IV, afterwards, the frame II are inserted to the frame I.

The glass fiber mesh is cut to 500 mm*27 mm in warp and weft direction respectively; and 500 mm*104 mm in warp and weft direction respectively.

2.3.2. Preparation of Fresh Mortar

The fresh base-coat is prepared with (95±4) mm consistence according to JGJ/T 70-2009.

2.3.3. Moulding and Curing

Following is the moulding and curing method:

1) The fresh base-coat is put in the moulding chamber among two strips, the frame III and frame IV, then tamped and flattened.
2) 2 pieces of 500 mm×27 mm mesh are put on each strips for base-coat anti-cracking test, or a piece of 500 mm×104 mm mesh on the moulding chamber for render anti-cracking test.
3) Steel ruler is put on each strip.
4) The fresh base-coat is put in the moulding chamber among two rulers, the frame III and frame IV, then tamped and flattened.
5) The mould and sample are then together settled in standard condition with (23±2) °C and (50±5) %RH.
6) Demoulded in 3d and the sample should be with (dr±0.2) mm* (50±0.5) mm* (500±2) mm, dr = thickness of the sample.
7) The sample should continue to be cured in standard condition for 28 days.

2.3.4. Test

The extruded mesh of the sample should be carefully cut after curing, and dr of the sample middle should be measured.

According to Figure 3, the sample is put in the fixture.

The pull-off test (see Figure 3) is performed at a tensioning speed of 2mm/min.

The curve of the load/displacement is recorded possibly until failure occurs. (see Figure 5)

The net ultimate displacement in the load/displacement curve is calculated as the value of the anti-cracking. The arithmetic mean value of net ultimate displacement of more than three valid specimens is used as the test result of three-point flexural tensile cracking resistance, which is accurate to 0.1mm.

3. Results and Discussion

3.1. Self-Developed Method and ETAG 004 Method

Table 1 shows the comparison of experimental results between the self-developed method and the ETAG 004 method.

Table 1. *Different experimental results of self-developed method and ETAG 004 method.*

VAE in dry-mortar/%		**1.0**	**2.5**	**4.0**
		92	52	152
		104	107	41
		4	100	165
	Test value/N	108	127	149
ETAG OO4				160
				126
				147
	Mean value/N	101	111	150
	Error/%	9.4	14.1	16.1

VAE in dry-mortar/%		1.0	2.5	4.0
Self-method	Test value/mm	2.5	4.5	6.7
		2.3	4.7	7.1
		2.6	4.5	6.9
	Mean value/mm	2.4	4.6	6.9
	Error/%	6.9	2.3	3.4

From table 1, it can be shown that the test results dispersion with the ETAG 004 test method is large, because of the difficulty in matching the flatness of the specimen with the metal gripper, and the difficulty in accurately controlling the tightening force of the metal gripper manually. Even if the invalid data is removed, the error of the remaining data is still large (9%-16%).

Otherwise, from Table 1, it can be seen that the test results error of self-developed test method is much smaller (2%-7%) because the horizontal end axis and the horizontal center axis of the drawing test machine are parallel to each other and can rotate freely.

3.2. Self-Developed Method and C/F

Figure 4 shows some experimental results of base-coat. The horizontal coordinate is the content (weight ratio) of polymer VAE emulsion powder in dry-mixed mortar. The left ordinate is the ultimate tensile failure displacement (cracking resistance), and the right ordinate is the C/F. The test method of C/F could be found in reference [7].

From figure 4, it can be shown that with the increase of VAE polymer powder content, C/F of the base-coat decreases rapidly at first, but the reduction of C/F slows down after VAE content reaches 2%.

Otherwise, by the self-developed method, the ultimate fracture displacement (cracking resistance) increased with the increase of VAE emulsion powder content. The self-developed experimental results are similar to those in the literature [21-23], and also similar to the law of relationship between the JS paint and the flexible putty flexibility (which cannot be directly quantified) and the polymer content in them. It shows that the self-developed test method can characteristic the cracking resistance of base-coat better than C/F.

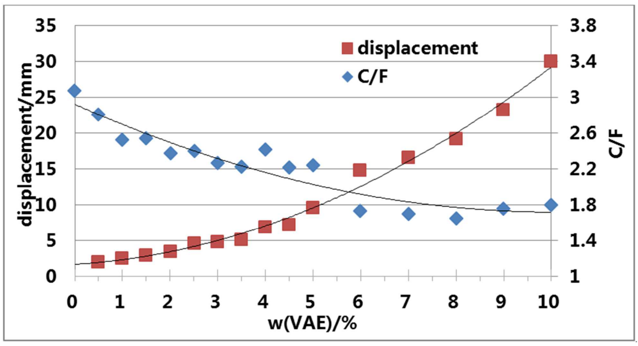


Figure 4. *Relationship between C/F and crack resistance of the base-coat with different VAE content.*

3.3. Self-Developed Method and Impact Resistance

Table 2 shows the parallel test results of impact resistance test conducted by relevant units organized by us. The test method of impact resistance could be found in reference [7]. In table 2, the denominator is the sample impacted times, and the numerator is the number of damage after the sample had been impacted.

Table 2. *Impact resistance test results of different test units and different samples.*

Sample manufacturer code		MS-1-1			MS-3			MS-5		
Tester code		YZ-1	YZ-5	YZ-6	YZ-1	YZ-5	YZ-6	YZ-1	YZ-5	YZ-6
Test results of different substrates	EPS	2/10	-	8/10	1/10	-	5/10	8/10	-	11/11
	Rock-wool board	3/10	1/8	-	7/10	1/9	0/12	8/10	11/11	8/12

From table 2, it can be shown that the impact resistance test results of different laboratories and different test personnel differ greatly. There are two reasons by our analysis: First, it is difficult to control the position of the glass fiber mesh in the impact resistance specimen made according to related standards [7-10] method; Second, in the evaluation of the impact resistance test results, the length and width of the crack are not clearly specified in related standards [7-10], and the length and width of the crack are observed by naked eye in the general laboratory, resulting in a large difference in the evaluation results between different personnel.

By the self-developed method, since the tension-displacement curve of the specimen during the test process is accurately recorded by the computer (figure 3), the difference between individuals caused by human eyes judging whether the crack is caused in the impact resistance test can be avoided (table 2).

By the self-developed molding method [25], due to the fixed thickness of the strip and steel ruler (3mm±0.1mm and 1mm±0.1mm, respectively), the small width of the specimen (50mm±0.5mm) and the glass fiber mesh was pressed by the steel ruler during the molding process, the thickness of the specimen itself and the position of the glass fiber mesh are less affected by human factors (the error is less than 0.2mm), which effectively reduces the error between different laboratories and different people. Therefore, the repeatability and regularity of the cracking resistance test results of the self-developed method are much better than that of the impact resistance test results (table 1, table 2 and figure 4).

The self-developed test method can quantitatively test the flexural-displacement curve of specimens with mesh and without mesh (Figure 4, figure 5), so that the difference in cracking resistance of different composition materials (including mortars, glass fiber mesh and their positions) can be accurately tested.

It can be seen from figure 4, the ultimate flexural displacement (cracking resistance) of the base-coat is almost linearly positively correlated with the content of polymer

VAE latex powder in it.

3.4. Self-Developed Method and Transverse Deformation

The forming of specimens for transverse deformation [22-24] is difficult, which makes low survival rate of specimens (about 50%). The forming mould of the self-developed method is detachable [25], so the forming efficiency is higher (≥90%). When testing transverse deformation, the middle half ring (test head) is pressed down, and the failure process of the specimen can hardly be observed; while the central horizontal axis of the self-developed method is pulled up, so the actual cracking process of the specimen can correspond to the data on the computer in real time and one by one (figure 5), which is more convenient for analysis. In addition, the diameter of the middle half ring (test indenter) for testing transverse deformation is too large (Φ100mm), which is not suitable for the testing of large deformation specimens. The diameter of the central horizontal axis of the self-developed method is Φ25±0.1mm, so specimens with large-scale deformation can be tested. More importantly, glass fiber mesh cannot be added to the transverse deformation specimen, which is far from the actual situation of ETICS. By the self-developed molding method, the glass fiber mesh can be easily added to the specimens and can be precisely positioned.

3.5. Relationship of Test Results Between Base-Coat and Render with Mesh

Figure 5 shows the experimental results of cracking resistance of a base-coat specimen and its corresponding render specimen with mesh detected by the self-developed method. Where, the horizontal coordinate is the flexural displacement, mm; the ordinate is the pull, N.

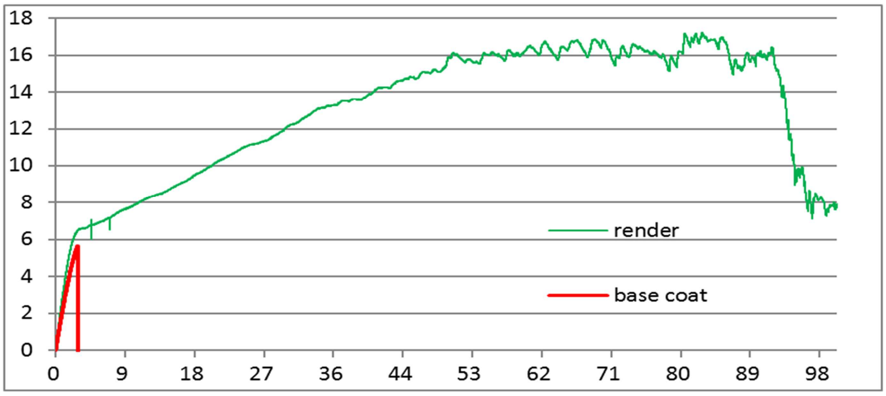


Figure 5. *Load-displacement curves.*

From figure 5, it is shown that the load-displacement curve of the render with mesh is obviously different from that of the base-coat without mesh. The initial cracking flexural displacement of render is almost the same as that of base-coat. It can be seen that there is a good correlation between the render and the base-coat. In the load/displacement curve of the render, every fluctuation corresponds to almost one crack in the specimen, which quantitatively reveals the important role of the glass fiber mesh. For the render, whether cracking is mainly determined by the cracking resistance of the base-coat; whereas, whether broken depends mainly on the quality of the glass fiber mesh.

3.6. The Effect of the Position of the Mesh on the Crack Resistance of the Render

Tests was carried out in order to understand the influence of the position of the glass fiber mesh in the render and the influence of the warp/weft of the glass fiber mesh on the cracking resistance of the render. Table 3 shows part of the test results, where, 3+1 means that the thickness of mortar under the glass fiber mesh is 3mm, and the thickness of mortar on the glass fiber mesh is 1mm; 1+3 is the opposite of 3+1; w means that the weft direction of the glass fiber mesh is consistent in the length direction of the specimen, and without w means that the warp direction of the glass fiber mesh is consistent in the length direction of the specimen. Maintenance and testing methods of all specimens are the same.

Table 3. *Influence of the position and warp/weft orientation of the mesh in the render on the crack resistance.*

Mesh in warp and weft direction and in different position	3+1	1+3	(3+1) w
Cracking resistance/mm	40.6	2.4	32.9

It can be seen from table 3, within the test range, the position of the glass fiber mesh in the render has a great influence on the cracking resistance of the render, while the warp and weft orientation of the glass fiber mesh has a relatively small influence on the cracking resistance of the render.

The effect of the position of the glass fiber mesh on the cracking resistance of the render is so large which has not been quantitatively described by others.

4. Conclusions

The self-developed three-point flexural tensile test method of cracking resistance, as well as the obtained displacement, is more accurate and repeatable than the test results of C/F, impact resistance, axial tensile strength, and can better characterize the cracking resistance of base-coat and render. The specimens forming method by self-developed is easier than that of transverse displacement specimens.

The self-developed three-point flexural tensile cracking resistance test method can directly compare the relationship between specimens with mesh and without mesh.

The three-point flexural tensile test method developed by ourselves can accurately test the function of glass fiber mesh in the render.

The cracking resistance of base-coat is positively correlated with the content of VAE polymer powder.

The anti-cracking effect of the glass fiber mesh in the render is very obvious, and the position of the glass fiber mesh has a great influence on the anti-cracking of the render. When the position of the glass fiber mesh is fixed, the cracking of the specimen with mesh mainly depends on the cracking resistance of the base-coat; whereas, whether broken depends mainly on the quality of the glass fiber mesh.

5. Recommendation

It is suggested that more research should be studied for analyzing the influence of various components to the cracking-resistance of the base-coat by the new three-point flexural tensile test method of cracking resistance.

The insulation materials (EPS, XPS, PU, rockwool, etc.) used in ETICS have different properties (especially dimensional stability), and different base-coat are required to support them. It is suggested that the corresponding cracking resistance index of base-coat for different insulation materials should be studied by the new test method.

The position of fiber glass mesh in render is very important for the cracking resistance of ETICS. It is suggested to establish a mathematical model to simulate and calculate the specific effects of different positions of glass fiber mesh on the cracking resistance of ETICS.

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