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Strength Characteristics of Styrene-Acrylic Cement Composite

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Abstract. Styrene-acrylic cement composite (SACC) is prepared by using styrene-acrylic emulsion, cement, etc. The change rules of tensile strain-stress curve, tensile strength and tensile modulus under the three factors: liquid to powder ratio, cement ratio and packing type were investigated through the method of orthogonal experiment. The results show that liquid to powder ratio is the main factor influencing the strength characteristics of SACC. With the increase of liquid to powder ratio, the flexibility of SACC is gradually enhanced. With the decrease of liquid to powder ratio, tensile strength and tensile modulus is increased. When the liquid to powder ratio is at 1:0.85, with the increase of cement ratio, peak stress and strain before the peak of the tensile strain-stress curve is increased. Tensile strength and tensile modulus have an increased tendency with the increasing of cement ratio. Compared with heavy calcium carbonate and quartz flour, talcum powder has a stronger effect on the tensile strength and tensile modulus of SACC. The influence of liquid to powder ratio, cement ratio and packing type to SACC is arranged as: liquid powder ratio, packing type, cement ratio. Polymer cement composite with average polymer-cement ratio used for joint sealing materials is feasible.

1. Introduction
Polymer cement composite material is a two-component material formed by cement hydration reaction and cross-linked curing of polymer emulsion [¹]. This material combines the performance characteristics of organic polymer materials and inorganic silicate materials. With the deepening of its research and application of extension, this material is widely used in the repair and maintenance of pavement cracks [²], construction waterproof [³] and other fields.

Scholars at home and abroad have done a lot of research on this material, Afridi [⁴], Ohama [⁵-⁶], Al-Zahrani [⁷], Zhong Shiyun. The preparation methods, mechanical properties, and modification mechanisms of polymer-modified cement mortars and concretes with lower poly-ash ratios were studied, and it was found that polymer materials can effectively improve the material's water retention, adhesion properties, impermeability, etc. Dong Fengliang [⁸], Yu [⁹], Nakamori [¹⁰] studied the tensile properties, elongation at break, flexibility at low temperatures, and durability of polymer cement waterproof coatings with high poly-ratio etc. found that it has good tensile deformation properties, durability, waterproof properties. However, less research has been conducted on polymer cement composites with moderate polycondensation ratios.

VAE emulsion, pure acrylic emulsion, styrene-acrylic emulsion, styrene-butadiene latex, etc. are
common polymer emulsions, among which the styrene-acrylic emulsion has better compatibility with cement, lower production cost, strong versatility, and wide application [11]. It is an ideal raw material for preparing polymer cement composites. In this paper, styrene-acrylic emulsion-cement composites with moderate poly-ratio were prepared by using styrene-acrylic emulsion and cement materials. Orthogonal test method was used to analyze the influence of three factors of liquid to powder ratio, cement ratio and packing type on the tensile stress-strain curve, tensile strength and tensile modulus, according to the test results, the level of each factor was optimized. The feasibility of using polymer cement composites as pavement filling materials was proposed.

2. Materials and methods

2.1 Raw materials

① Polymer emulsion: Acronal S400 styrene-acrylic emulsion (solid content: 55%±1%; pH value: 7.0~8.3). ② Cement: "Bobai" brand 42.5 ordinary portland cement. ③ Packing: talcum powder, quartz powder and heavy calcium carbonate. ④ Auxiliaries: polycarboxylic acid sodium salt dispersant, dodecyl alcohol ester film coalescing agent and metal soap defoamer.

2.2 specimen preparation and test methods

Selection of four factors and three level orthogonal (L₉(3⁴)) , liquid to liquid ratio (ratio of emulsion mass to total powder mass), cement ratio (percentage of cement mass to total powder mass) and packing type are experimental factors, which are denoted by A, B, and C, respectively. The corresponding level of each factor is listed in Table 1. Tensile stress-strain curve, tensile strength, and tensile modulus were used as test indexes. Orthogonal test programs and raw material ratios are listed in Table 2. The amount of each additive was: defoamer and dispersant accounted for 3% and 7% of the total mass of the emulsion, filler and cement, respectively, and the film-forming agent accounted for 5% of the emulsion mass. The preparation process of the test piece is as follows: ① Add dispersant, filming aid, half-expansion defoamer and stir evenly in the emulsion. ② Add the dry-blended powder to the emulsion while stirring, and use the high-speed electric motor. The mixer is stirred for 10 minutes at a speed of 700r/min. ③ The other half defoamer is added, and the mixture is stirred by electric first and then manually until there is no bubble in the mixture. ④ Inject the mixture into the mold with a syringe. ⑤ After 4 days of indoor curing, remove the mold, and then continue curing for 28 days. The prepared specimen is shown in Figure 1.

The test adopts HS-3001B electronic tensile testing machine for tensile test. During the test, the test piece was stretched to the breakpoint ratio (taken 10%) at a rate of 5 mm/min using the tensile jig shown in figure 2. Each set of tests was repeated 3 times and the results were averaged.

| Liquid to powder ratio (A) | Cement ratio (B) | Packing type (C) |
|---------------------------|------------------|------------------|
| 1:0.85                    | 10%              | Talcum powder    |
| 1:0.65                    | 35%              | Heavy calcium carbonate |
| 1:0.45                    | 60%              | Quartz powder    |

Table 2 Orthogonal experiment scheme and mix proportion

| Sample | A | B | C | Error | Emulsion | Packing | Cement | Deforming agents | Dispersing agents | Coalescing agents |
|--------|---|---|---|-------|----------|---------|--------|------------------|-------------------|-------------------|
| S1     | A₁ | B₁ | C₁ | D₁   | 100      | 76.5    | 8.5    | 0.56             | 1.30              | 5                 |
| S2     | A₁ | B₁ | C₂ | D₂   | 100      | 55.3    | 29.7   | 0.56             | 1.30              | 5                 |
| S3     | A₁ | B₁ | C₁ | D₃   | 100      | 34.0    | 51.0   | 0.56             | 1.30              | 5                 |
| S4     | A₂ | B₁ | C₃ | D₂   | 100      | 58.5    | 6.5    | 0.50             | 1.16              | 5                 |
| S5     | A₂ | B₁ | C₁ | D₃   | 100      | 42.3    | 22.7   | 0.50             | 1.16              | 5                 |
3. Results and discussion

3.1 Analysis of tensile stress and strain curves

The stress-strain curve is a comprehensive manifestation of the mechanical properties of the material. Figure 3 shows the tensile stress-strain curves for different sets of specimens at different liquid to powder ratios.

![Figure 3 Tensile stress-strain curves in different ratio of liquid to powder](image)

It can be seen that: (1) The ratio of liquid to powder determines the overall shape of the stress-strain curve, which is the main influence factor of the stress-strain curve. (2) The slope of the rising section of the curve gradually decreases with the increase of the liquid to powder ratio. When the same stress is reached, the corresponding strain gradually increases. This shows that SACC’s ability to resist tensile stress weakens with increasing liquid to powder ratio in the elastic deformation stage. (3) With the increase of liquid to powder ratio, the pre-peak strain increases gradually and the
yield point gradually shifts backwards. This shows that with the increase of liquid to powder ratio, the elastic stage of SACC is increasing and the elastic deformability gradually increases. ④ With the ratio of liquid to powder increasing, the peak stress gradually decreases, indicating that the liquid to powder ratio decreases the tensile strength of the SACC. ⑤ As the liquid to powder ratio increases, the curve gradually shows a larger platform segment, SACC peak stress The deformation generated in the vicinity gradually increased, indicating that the increase of liquid to powder ratio increased the deformation capacity of SACC and gradually changed it from brittle materials to flexible materials. ⑥ The change in cement ratio has little effect on the overall shape of the stress-strain curve. It can be seen from Figure 3 that when the ratio of liquid to powder is 1:0.85, the effect of cement ratio change on the curve is more obvious. The trend is that with cement With the increase of the ratio, the peak stress and the pre-peak strain are all increased. When the ratio of liquid to powder is 1:0.65 and 1:0.45, the change of the cement ratio has no obvious effect on the curve. ⑦ The influence of packing type on the SACC tensile stress-strain curve cannot be clearly observed from the curve and further single-factor studies are required.

3.2 Tensile strength analysis

Tensile strength is the peak stress that the specimen reaches during the stretching process and it reflects the material's ability to resist tensile loading. Table 3 lists the test results of tensile strength indicators in orthogonal tests.

| Sample | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  | S9  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Tensile strength | 0.314 | 0.249 | 0.267 | 0.203 | 0.259 | 0.216 | 0.168 | 0.180 | 0.221 |

| Factors                  | k1   | k2   | k3   | Range |
|--------------------------|------|------|------|-------|
| Liquid to powder ratio   | 0.277 | 0.226 | 0.190 | 0.087 |
| Cement ratio             | 0.228 | 0.230 | 0.235 | 0.006 |
| Packing type             | 0.265 | 0.211 | 0.217 | 0.054 |

Table 4 shows an analysis of the data. The trend of each factor's level change is shown in Figure 4. It can be seen that: ① Comparing the range of the three factors, liquid powder had the greatest influence on the tensile strength of SACC, followed by the packing type, and the cement ratio had the smallest effect. ② The tensile strength of SACC decreases with liquid to powder ratio increases, A1 to A2 segments, a tensile strength of from 0.277 MPa decreased to 0.226 MPa reduced by 18.4%, decrease is more significant, A2 to A3 sections, a tensile strength of from 0.226 MPa decreased to 0.190 MPa reduced of 15.9%, a slightly decreasing tendency slowed. ③ The proportion of cement 10% increased to 60%, tensile strength increased from 0.228 MPa to 0.235 MPa, only increased by 3%,
so the cement ratio has little effect on the tensile strength of SACC, only a slight increase as the proportion of cement increases Trends. ④ The tensile strength of SACC when adding talc powder is 26% higher than that when adding heavy calcium carbonate, and the effect of heavy calcium carbonate and quartz powder on tensile strength is similar, so SACC has relatively high tensile strength when adding talcum powder.

3.3 tensile modulus analysis
Tensile modulus is defined as the stress value corresponding to 60% of the original specimen width when it is stretched. It reflects the ability of the material to resist deformation under external force to a certain extent. The stronger the ability to resist deformation, and vice versa, the weaker the material's resistance to deformation. Table 5 shows the tensile modulus index test results in the orthogonal test.

| Sample | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
|--------|----|----|----|----|----|----|----|----|----|
| Tensile modulus | 0.298 | 0.245 | 0.264 | 0.203 | 0.259 | 0.216 | 0.161 | 0.178 | 0.209 |

Table 6 Range analysis results of orthogonal experiment

| Factors | Liquid to powder ratio | Cement ratio | Packing type |
|---------|------------------------|--------------|--------------|
| k₁      | 0.269                  | 0.221        | 0.255        |
| k₂      | 0.226                  | 0.227        | 0.207        |
| k₃      | 0.183                  | 0.230        | 0.215        |
| Range   | 0.086                  | 0.009        | 0.048        |

Figure 5: Change trend chart of factors and levels

From the range analysis results in Table 6 and the trend of factor level changes (Figure 5), it can be seen that: ① With the mix ratios studied in this paper, the tensile modulus of SACC is between 0.161 MPa and 0.298 MPa. Reference is made to the grading standards mentioned in ISO/DIS 11600-2000[12] and [13]. Under room temperature, when the tensile modulus of gapfill material is not more than 0.4 MPa, it is a low-modulus caulking material. The SACC can be positioned on low-modulus caulking materials. ② The order of influence of the three factors on the tensile modulus of SACC is: liquid to powder ratio > packing type > cement ratio. ③ Liquid to powder ratio from 1:0.85 increased to 1:0.45, tensile modulus decreased from 0.269MPa to 0.183MPa, a decrease of 32% The decrease is more obvious. At the same time, it can be seen that the tensile modulus decreases linearly with the increase of the ratio of liquid to powder. ④ The proportion of cement increases from 10% to 60%, and the tensile modulus increases from 0.221MPa to 0.230MPa. The increase of 4% shows that the tensile modulus is affected little by the proportion of cement, and only slightly increases with the increase of the proportion of cement. ⑤ SACC tensile model when adding talc filler The amount is higher than the tensile modulus of the addition of heavy calcium carbonate and quartz powder.

3.4 Discussion
Through the above analysis, it was found that the three factors had different degrees of influence on the tensile strength of the SACC, and the liquid to powder ratio was the main factor that affected the tensile strength characteristics of the SACC. In view of this, using the scanning electron microscope to observe the specimens (S8, S5, S2) with three different liquid to powder ratios, Figure 6 shows the observation results.

![Figure 6 SEM observation results](image)

It can be seen that when the ratio of liquid to powder is 1:0.45 (S8), the continuous polymer film formed by the polymer curing accounts for the bulk of the material, the pores are densely distributed, and the pore sizes are large and small, making SACC a flexible material. The strength is low; the concentration of the powder in the emulsion is relatively low, and it mainly acts as a filling. Some of the cement is wrapped by the polymer film and cannot fully perform the hydration reaction, and the effect of increasing the proportion of cement on the material strength is not great. When the liquid to powder ratio is 1:0.65 (S5), the concentration of the powder is increased, and the cement structure formed by cement hydration distributes among them, some of the large-pore pores are filled, the number of pores is reduced, and the strength of the SACC is increased. Powder liquid ratio of 1:0.85 when (S2), wrapped cement significantly reduced, fillers and rubber coagulation structure more uniformly distributed in the polymer phase, and the polymer film crosslinked with each other, the aperture can be further reduced, so SACC strength is further improved.

The fibrous structure of talc \(^{[3]}\) increases the ability of SACC to withstand tensile loads and increases the tensile strength and tensile modulus of SACC. The heavy calcium carbonate particles are rough and have a certain activity. The quartz powder is also rough. Both of them can improve the tensile strength and modulus of the SACC, but compared to the fibrous structure of the talc powder on the tensile strength and modulus. The reinforcement effect of heavy calcium carbonate and quartz powder is weak, so the tensile strength and tensile modulus of SACC when adding talc are relatively high.

According to the ratio range of this article, the liquid to powder ratio is 1:0.85, the proportion of cement is 60%, and all the tensile strength indexes of SACC when the filler is talc are at a relatively high level, which is the preferred ratio. Refer to ISO/DIS 11600-2000 for grading standards for gapfill materials. The tensile modulus of styrene-acrylic emulsion-cement composites prepared in accordance with the preferred ratio is not greater than 0.4MPa, and can be positioned on low modulus sealing materials. After further research on the optimization of raw materials and blending ratios, it is feasible for polymer cement composites to be used as caulking materials.

4. Conclusions

(1) The liquid to powder ratio is the main factor affecting the tensile strength of SACC. With the increase of the liquid to powder ratio, the yield point of the tensile stress-strain curve is shifted backwards, and the slope and peak stress of the ascending segment are reduced. Pre-peak strain with the increase, the platform section gradually expands, and SACC gradually changes from brittle materials to flexible materials. With the decrease of liquid to powder ratio, both tensile strength and tensile modulus increase.

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(2) The effect of cement ratio on the tensile stress-strain curve of SACC is mainly manifested in the case of a lower ratio of liquid to powder 1:0.85. As the proportion of cement increases, the peak stress and pre-peak strain of the curve increase; when the liquid powder is large, the proportion of cement has no obvious effect on the tensile stress-strain curve; the cement ratio has no significant effect on the tensile strength and tensile modulus of SACC, but only increases with the increase of cement proportion.

(3) Talcum powder has a significant effect on the tensile strength and tensile modulus of SACC, heavy calcium carbonate and quartz powder have a relatively weaker effect on the tensile strength and tensile modulus.

(4) The order of influence of three factors on the tensile strength and tensile modulus of SACC is: liquid to powder ratio > packing type > cement ratio.

(5) Polymer cement composites with medium poly-ratio are feasible for use as joint sealing materials.

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