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Study on Tensile Mechanical Property of Styrene-acrylic Cement Composite Material

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Abstract: By using orthogonal experiment styrene-acrylic cement composite material (SCCM) was designed and prepared, its tensile mechanical properties were tested and analyzed. The results indicate that powder-liquid ratio determines the curing reaction forms of SCCM, which is the main factor influencing tensile mechanical property of SCCM. When powder-liquid ratio is low (0.45), the deformation performance and tenacity of SCCM are declined with the increase of cement content. When powder-liquid ratio is high (0.65, 0.85), the strength, deformation performance and tenacity of SCCM are increased with the increase of cement content, furthermore, the increase of performance will be more obvious if the powder-liquid ratio is higher. Talcum powder can improve the strength of SCCM while heavy calcium carbonate can improve its deformation performance and tenacity. When the powder-liquid ratio is 0.65, the cement content is 0.35, the packing type is heavy calcium carbonate, the tensile mechanical properties of SCCM are better, which has a great potential to be used as a building joint material.

1. Introduction
The polymer cement composite material [1] is a two-component polymer formed by blending organic high molecular polymer with cement, adding additives and fillers, and forming a reaction between polymer film and cement hydration. This kind of material combines the performance characteristics of organic polymer materials and inorganic silicate materials, and can be divided into two categories according to the level of polymer content. One is a rigid polymer cement composite with a low polymer-cement ratio. This kind of material is mixed with high-molecular polymer [2-4] in mortar or concrete to improve its workability [5], mechanical properties [6], durability [7-9], and can be used as various functional mortar [9] or repair material [10] etc. The other one is a flexible polymer cement composite material with a high polymer- cement ratio. Due to the high polymer content, a complex cross-linking curing reaction occurs between the organic high-molecular polymer and the cement, thereby exhibiting excellent bonding deformation performance [11-12] and waterproof performance [13]. At present, its research and application mainly focus on building waterproofing, such as polymer cement composite waterproof coating [14], sealant and so on.

In this study, styrene-acrylic emulsion cement composites (SCCM) with higher poly- ash ratio were prepared with styrene-acrylic emulsion, cement, fillers and additives. Through the design of orthogonal test, the tensile mechanical properties of SCCM were studied, and the influence of powder-latex ratio, cement content and filler type on the tensile mechanical properties of SCCM was explored.
According to the test results, the level of each factor was optimized. Compared with the relevant standards, we found that SCCM has great potential for use as a building joint sealant.

2. Experiment

2.1 Raw materials
Emulsion: styrene-acrylic emulsion. Cement: Shaanxi Qinling brand P.O 42.5R ordinary Portland cement. Filler: quartz powder (300 mesh), heavy calcium carbonate (500 mesh), and talcum powder (600 mesh). Auxiliaries: polycarboxylate sodium dispersing agent, metal soap defoaming agent and dodecyl alcohol ester coalescing agent. Table 1 gives the technical specifications of styrene-acrylic emulsions.

| Latex                  | Solid content | pH     | Particle size | T<sub>g</sub> | MFT |
|------------------------|---------------|--------|---------------|--------------|-----|
| Styrene-acrylic        | 56%~58%       | 7.0~8.0| 1.5μm         | -10°C        | 0°C |

2.2 Experiment Plan
Orthogonal experiments are used to balance the characteristics of dispersion and orderliness. In this experiment, an orthogonal test was designed using a L<sub>9</sub>(3<sup>4</sup>) orthogonal table. Two kinds of analysis methods, range analysis and variance analysis, were used to study the effect of three factors, powder-latex ratio (the ratio of powder quality to emulsion quality), cement content (cement quality to powder mass ratio), and filler type, on the tensile test indexes of the material. The level of each factor: Powder-latex ratio: 0.45 (A1), 0.65 (A2), 0.85 (A3). Cement content: 0.1 (B1), 0.35 (B2), 0.6 (B3). Filler type: quartz powder (C1), heavy calcium carbonate (C2), talc (C3).

In order to quantify the effect of each factor on the test index, the contribution rate \( \rho_i \) of factor \( i \) and the contribution rate \( \rho_e \) of error can be calculated by equations (1.1) to (1.4). The larger \( \rho \) is, the greater the contribution is. In the formula, \( Q_i^2 \) and \( Q_e^2 \) are the sum of squared deviations of factor \( i \) and experimental error, and the degrees of freedom are \( n_i \) and \( n_e \) respectively.

\[
\rho_i = \frac{Q_i^2 - n_i \left( \frac{Q_e^2}{n_e} \right)}{Q_i^2} \times 100\% \quad (1.1)
\]

\[
\rho_e = n_e \frac{Q_e^2}{n_e} \times 100\% \quad (1.2)
\]

\[
Q_i^2 = \sum Q_i^2 + Q_e^2 \quad (1.3)
\]

\[
n_e = \sum n_i + n_e \quad (1.4)
\]

2.3 Specimen preparation and test equipment
Sample preparation process: (1) Weighing: According to the mix proportion given in Table 2, the volume of defoaming agent and dispersing agent are 0.3% and 0.7% of the total mass of the emulsion and powder, respectively. The volume of coalescing agent is 5% of the mass of emulsion. (2) Liquid material preparation: dispersing agent, coalescing agent and half defoaming agent are blended into the emulsion in turn and mixed evenly. (3) Powder dispersion: the cement and filler are dry-blended and mixed. (4) Defoaming: Incorporate the remaining half of the defoaming agent, stir manually after electric stirring until there is no bubble in the mixture. (5) Pouring: mix the mixture into the mold curing for 4 days then remove the film and continue curing for another 24 days. The prepared specimen is shown in Figure 1.
Table 2. Experiment scheme and mix ratio

| Sample | Orthogonal scheme | Error | Latex | Powder lot | Matching/g |
|--------|-------------------|-------|-------|------------|------------|
|        |                  |       |       | Cement     | Packing    | Disperser agent | Coalescing agent | Defoaming agent |
| SC1    | 0.45 0.10 | 3     | 200   | 9.0        | 81.0       | 2.04            | 10            | 0.88            |
| SC2    | 0.45 0.35 | 1     | 200   | 31.5       | 58.5       | 2.04            | 10            | 0.88            |
| SC3    | 0.45 0.60 | 2     | 200   | 54.0       | 36.0       | 2.04            | 10            | 0.88            |
| SC4    | 0.65 0.10 | 2     | 200   | 13.0       | 117.0      | 2.32            | 10            | 1.00            |
| SC5    | 0.65 0.35 | 3     | 200   | 45.5       | 84.5       | 2.32            | 10            | 1.00            |
| SC6    | 0.65 0.60 | 1     | 200   | 78.0       | 52.0       | 2.32            | 10            | 1.00            |
| SC7    | 0.85 0.10 | 2     | 200   | 17.0       | 153.0      | 2.60            | 10            | 1.12            |
| SC8    | 0.85 0.35 | 3     | 200   | 59.5       | 110.5      | 2.60            | 10            | 1.12            |
| SC9    | 0.85 0.60 | 3     | 200   | 102.0      | 68.0       | 2.60            | 10            | 1.12            |

The test uses the HS-3001B electronic tensile testing machine shown in Figure 2. The specimens are stretched to a breaking point ratio of 10% at a loading rate of 5 mm/min, and its force-displacement curve is recorded. The results were taken as the arithmetic average of the three tests.

Table 3. Test results of test index

| Sample | $f$/MPa | $E$/MPa | $e_t$ | $E_b$/% | $T_f$/ J/cm³ | $T_p$/ J/cm³ | $T_o$/ J/cm³ |
|--------|---------|---------|-------|---------|--------------|--------------|--------------|
| SC1    | 0.168   | 0.161   | 0.923 | 216.8   | 0.054        | 0.196        | 0.314        |
| SC2    | 0.180   | 0.178   | 0.743 | 197.3   | 0.044        | 0.191        | 0.295        |
| SC3    | 0.221   | 0.209   | 0.954 | 194.4   | 0.047        | 0.192        | 0.283        |
| SC4    | 0.203   | 0.203   | 0.588 | 159.9   | 0.045        | 0.168        | 0.284        |
| SC5    | 0.259   | 0.259   | 0.633 | 155.3   | 0.042        | 0.188        | 0.292        |
| SC6    | 0.216   | 0.216   | 0.656 | 182.2   | 0.042        | 0.216        | 0.332        |
| SC7    | 0.314   | 0.298   | 0.432 | 111.8   | 0.035        | 0.133        | 0.231        |
| SC8    | 0.249   | 0.245   | 0.438 | 146.8   | 0.035        | 0.174        | 0.307        |
| SC9    | 0.267   | 0.264   | 0.492 | 141.7   | 0.044        | 0.199        | 0.335        |

3. Results and Discussion
3.1 Stress-strain curve
Figure 3 shows the tensile stress-strain curves for each set of specimens. From the perspective of the shape of the curve, each group has a significant rising distinct and a falling one, and there is a sudden decrease in the falling distinct of some groups. This is because the pull-off of the material is not the simultaneous occurrence of the entire cross-section, but it gradually develops from one part to the entire cross-section, and the cross-sectional area of the material suddenly decreases after incomplete pulling, resulting in an instantaneous increase in strain.

From SC7, SC8, SC9 to SC4, SC5, SC6 to SC1, SC2, and SC3, the powder-latex ratio gradually decreases, the slope of the curve of rising distinct gradually decreases, the plastic deformation becomes more and more obvious, and the falling distinct also tends to be gentle. This shows that as the polymer content increases, the polymer weakens the stiffness characteristics of SCCM and effectively improves its bond deformation capacity. Thus, the strength gradually decreases and the deformability gradually increases.

When the powder-latex ratio is 0.45, as the cement content gradually increases, the strength of SCCM does not change significantly, and the falling distinct of the curve shifts to the left, indicating that its deformation ability decreases. When the powder-latex ratio is 0.65, as the cement content gradually increases, the strength and deformability of the SCCM slightly increases. When the powder-latex ratio is 0.85, as the cement content gradually increases, the strength of the SCCM increases significantly, and the falling distinct of the curve shifts to the right, indicating that the deformation capacity increases. It can be seen that the effect of cement content on the stress-strain curve is closely related to the powder-latex ratio and there is a complex coupling relationship between cement content and powder-latex ratio.

The influence of filler type on SCCM tensile stress-strain curve is not obvious, and further study on filler type with single factor method is needed.

3.2 Analysis of Strength Indexes

![Figure 3: Tensile stress-strain curves](image-url)
Tensile strength \( f_t \) is the peak stress reached when SCCM is under tensile load. Tensile modulus \( E_t \) is the corresponding stress when SCCM’s tensile length is 60% of the original width. These two indexes reflect the ability of SCCM to resist tensile load. Table 3 shows the test results for each set of specimens’ \( f_t \) and \( E_t \). The results of calculating the range \( R \), significance, and contribution \( \rho \) for each factor are given in Table 4. Figure 4 shows the trend of \( f_t \) and \( E_t \) with the various factors.

From the results of range analysis and variance analysis of the three factors, it can be seen that the extreme difference of powder-latex ratio is the biggest, and the effect on the SCCM \( f_t \) and \( E_t \) is the most significant and the contribution is the largest, and both the \( f_t \) and the \( E_t \) significant increase with the increase of powder-latex ratio. The impact of filler type followed, the specific performance is: when using talc powder as filler, \( f_t \) and \( E_t \) of SCCM are slightly higher when using quartz powder than when heavy calcium carbonate was selected. The extreme difference of cement content is very small only 0.006, and the impact and contribution to the two strength indicators can be ignored. However, according to Figure 4, we can see that with the increase of cement content, the two strength indicators of SCCM have trends of increase.

This is because SCCM's curing reaction can be divided into two parts: Volatile curing is the evaporation of water in the emulsion, and the emulsion encapsulates the inorganic powder to form a continuous gel-like elasto-plastic film; the reaction curing is a hydration reaction of the cement, and the resulting hydration product curing crosslinked network in the emulsion with the macromolecule polymerization chain. When powder-latex ratio as increased from 0.45 to 0.85, the concentration of the powder increased from a very low level to a relatively high level, which in turn caused the curing reaction of the SCCM to change from the volatilized solidification to the reaction solidification, and the material gradually changed to a rigid material. Therefore, the effect of powder-latex ratio on the two strength indexes is the greatest. In contrast, the effect of cement content on the strength indexes is affected by the change of powder-latex ratio. It can only be seen that the \( f_t \) and \( E_t \) of SCCM tend to increase with the increase of cement content. The influence of filler type on two strength indexes is reflected in the different modification effects of different fillers on SCCM. Compared to heavy calcium carbonate and quartz powder, the fibrous structure of talc powder improves the integrity of SCCM and is effective. As a result, there is a significant effect on the two strength indicators. In addition, the selected quartz powder (300 mesh) has a large particle size of the calcium carbonate (500 mesh), which, to some extent, increases the roughness of the inorganic components and further enhances the strength of the SCCM.

### Table 4 Analysis of strength index

| Index | Element | \( \rho \) | \( Q^2 / n_f \) | \( Q^2 / n_t \) | \( F_t \) | Significance | \( \rho_t \) | \( \rho_t \) |
|-------|---------|------|----------|----------|------|----------|------|------|
| \( f_t \) | A | 0.087 | 0.0171 | 37.98 | *** | 55.70% |
| | B | 0.006 | 0.0001 | — | — | — | — | — |
| | C | 0.054 | 0.0078 | 17.36 | *** | 24.70% |
| Error | — | 0.0005 | — | — | 19.60% |
| \( E_t \) | A | 0.086 | 0.0167 | 43.55 | *** | 60.60% |
| | B | 0.009 | 0.0002 | — | — | — | — | — |
| | C | 0.048 | 0.006 | 15.65 | *** | 20.90% |
| Error | — | 0.0004 | — | — | 18.50% |

Note: "***" stands for very strong significance; "**" stands for strong significance; "*" stands for poor significance; ":-" stands for no effect;
3.3 Analysis of deforming indexes

The peak strain $\varepsilon_t$ is the strain corresponding to the SCCM is stretched to peak stress, and the elongation at break $E_b$ is calculated according to Equation (2.1). These two indicators reflect the deformation properties of SCCM.

$$E_b = \frac{W_1 - W_0}{W_0} \times 100\% \quad (2.1)$$

In the equation, $W_0$ is the initial width of the SCCM in the test piece; $W_1$ is the width when test piece is stretched to the breakpoint ratio. Table.3 shows the test results of $\varepsilon_t$ and $E_b$ for each set of specimens. The calculation results of the extreme difference $R$, significance, and contribution $\rho$ for each factor are given in Table.5, and the trend of $\varepsilon_t$ and $E_b$ with various factor are showed in Figure 5.

It can be seen that powder-latex ratio is still the decisive factor influencing the two deformation indexes of SCCM, and the contribution rate has reached 74%~86%. With the increase of powder-latex ratio, the $\varepsilon_t$ and $E_b$ of SCCM are obviously decreased. The reason is the same as the mechanism of the effect of powder-latex ratio in analysis of strength indexes. For $\varepsilon_t$, the effect of cement content and filler type on deforming indexes of SCCM is significant, but the contribution rate is very low. This may be due to the fact that the change in the level of powder-latex ratio is too great for the SCCM modification, which masks the effects of changes in the levels of the other two factors. For $E_b$, the filler type has a significant effect and a high contribution rate. Combined with Figure.5, the impact of filler type on $E_b$ is reflected in: heavy calcium carbonate is a kind of weak polar substance, which has a certain activity, and can effectively improve the quality of the high-molecular polymer film in emulsion. It can effectively extend the limit width when the SCCM stretch reaches the break point ratio, thereby increasing its elongation at break.

Table.5 Analysis of deformation index

| Index | Element | $R$ | $Q^2 / n_1$ | $Q^2 / n_2$ | $F_i$ | Significance | $\rho_i \ (\rho_e)$ |
|-------|---------|-----|-------------|-------------|------|--------------|------------------|
| $\varepsilon_t$ | A | 0.419 | 0.399 | 127.51 | *** | 85.40% |
| | B | 0.096 | 0.021 | 6.69 | ** | 3.80% |
| | C | 0.065 | 0.013 | 4.03 | *** | 2.00% |
| | Error | - | 0.003 | - | - | 8.80% |
| $E_b$ | A | 69.4 | 10845.2 | 70.53 | *** | 74.70% |
| | B | 9.9 | 225.9 | - | - | - |
| | C | 28.1 | 1782.7 | 11.59 | *** | 11.30% |
| | Error | - | 153.7 | - | - | 14.00% |

Note: "***" stands for very strong significance; "**" stands for strong significance; "*" stands for poor significance; "-" stands for no effect;
3.4 Analysis of energy loss

The plastic section of the SCCM is defined as the section between the two points where the stress in the ascending and descending sections of the tensile stress-strain curve is 0.9 ft (as shown in Figure.6). The elastic section is defined before the plastic section. The total area enclosed by the curve is the total toughness $T_o$. The area surrounded by the elastic section of the curve is the elastic toughness $T_e$, and the area surrounded by the plastic section is the plastic toughness $T_p$. $T_o$, $T_e$ and $T_p$ reflect the energy loss characteristics of various sections of the SCCM during stretching.

Figure.7 shows the effect of powder-latex ratio and cement content on the $T_o$, $T_e$ and $T_p$ of materials. It can be seen that when powder-latex ratio is 0.45, as cement content increases, $T_e$ and $T_p$ do not change significantly while $T_o$ gradually decreases. When powder-latex ratio is 0.65, $T_e$ does not change significantly with increasing cement content while $T_p$ and $T_o$ gradually increase. When powder-latex ratio is 0.85, $T_e$ increases slightly with increasing cement content while $T_p$ and $T_o$ increase significantly. This is because when powder-latex ratio is 0.45, the concentration of the powder in the emulsion is low, and the gel produced by cement hydration will not only fail to form a cross-linked network with the polymer chains, but will hinder the formation of elasto-plastic films in the emulsion. The greater the cement content, the more obvious the obstruction effect, which in turn reduces $T_o$. When the powder-latex ratio is 0.65, the concentration of powder is increased. The gel formed by cement hydration begins to form a crosslinked structure with the polymer chains. The greater the amount of cement, the denser the cross-linked structure, $T_p$ and $T_o$ also increase. When powder-latex ratio is 0.85, the concentration of powder reaches a higher level. At this time, increasing the cement content makes the cross-linked structure formed inside the SCCM gradually develop into a cross-linked network, and the increasing effect of $T_p$ and $T_o$ is more obvious.

Figure.8 shows the effect of filler type on the materials $T_o$, $T_e$ and $T_p$. It can be seen that the SCCM $T_e$, $T_p$ and $T_o$ are all large when the filler is heavy calcium carbonate. This is because heavy calcium carbonate has a weak buffering effect, which can regulate the hydration rate of cement and the film formation process of emulsions, resulting in a relatively high-quality cross-linked network in SCCM, thereby increasing its toughness.
3.5 Discussion
According to the ratio range of this article, when powder-latex ratio is 0.45, the SCCM tends to be flexible. When the powder-latex ratio is 0.85, the SCCM is biased. When the powder-latex ratio is 0.65, the SCCM is soft and soft, and when the powder-latex ratio is 0.65, 0.6 cement content makes SCCM have better tensile mechanical properties and toughness; SCCM has higher strength when talc is used as filler, and SCCM has better deformability and toughness when using heavy calcium carbonate. Reference standard ISO/DIS 11600 [15], JC/T 881[16], JC/T 976[17] requirements for tensile modulus of joints in building joints: Tensile modulus of joint compound at room temperature It should be no more than 0.4 MPa, the powder-latex ratio is 0.65, the cement content is 0.6, and the SCCM prepared with heavy calcium carbonate has good tensile properties and tensile modulus meets requirements. After further optimization of materials and ratio, SCCM It has great potential for use as a joint filler in construction.

4. Conclusion
(1) The powder-latex ratio determines the form of SCCM curing reaction and is the main factor affecting its tensile mechanical properties. When the powder-latex ratio is 0.45, the SCCM has good deformation properties; when the powder-latex ratio is 0.85, the SCCM strength is high; when the powder-latex ratio is 0.65, the strength and deformation properties are in between.

(2) The modification effect of cement content on SCCM indicators is affected by powder-latex ratio. When powder-latex ratio is 0.45, the deformability and toughness of SCCM become worse as the cement content increases. When powder-latex ratio is 0.65 or 0.85, the strength, deformability and toughness of SCCM increase with the increase of cement content. Gradually increase the degree, the increase of powder-latex ratio is 0.85;

(3) Talc can increase the strength of SCCM, and heavy calcium carbonate can improve the deformation and toughness of SCCM
When powder-latex ratio is 0.65, the cement content is 0.35, and the filler type is heavy calcium carbonate, the tensile mechanical properties of SCCM are all better, and it has great potential as a joint sealing material for construction joints.

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