Effect of Silicone Waterproofing Agent on the Properties of Ceramic Recycled Aggregate Cement Mortar

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Abstract. The ceramic waste were crushed and sieved to replace partially the sand to prepare cement mortar as aggregate, and different quality of silicone waterproofing agents were added to study the effects on the mechanical properties and water absorption under natural curing conditions. The experimental results indicated that through 28 days of natural curing, the flexural strength of ceramic recycled aggregate cement mortar was 1.18% higher than that of ordinary cement mortar, the compressive strength is 2.94% lower, the water absorption is 0.5% lower, which means the performance difference is not obvious. With the increasing amount of the silicone waterproofing agent, the compressive and flexural strength of the samples gradually decreased, and the water absorption decreased first and then increased. When the amount of waterproofing agent is 2%, the comprehensive performances of the sample were the best: the 28-day flexural strength was 6.84 MPa, the compressive strength was 42.8MPa, and the water absorption was 4.66%.

1. Introduction
At present, China is in an important period of economic construction and development. As the process of urbanization is accelerating, the construction industry has developed rapidly, and the amount of concrete used has increased year by year, causing a large number of resources and energy consumption [1]. The demand for sand as concrete aggregate is huge, according to the report “Uncovering sand mining’s impacts on the world’s rivers” released by the World Wide Fund for Nature (WWF) in August 2018, the annual global volume of sand and gravel aggregates can reach about 50 billion tons, of which 30 billion tons are used in the construction industry, as the second-largest natural resource consumed after water resources. The annual consumption of sand and gravel in China exceeds 20 billion tons, which is the largest natural resource currently exploited. Recently, Nature commented that the current mining speed of sand and gravel had exceeded its natural recovery speed [2]. The problem of lack of natural aggregate resources has become increasingly serious, and even caused a series of problems such as floods, droughts, and environmental pollution. For such non-renewable natural resources, measures should be taken to avoid waste.

As the largest ceramic producing country, China’s ceramic industry produces more and more ceramic wastes during the process of production, transportation, installation, and use. Ceramics are hard to weather and rot, and the cost of recycling is too high, therefore, most companies still choose landfills, which cause a lot of waste of land and natural resources. The recycling of ceramic waste has become a...
current research hotspot [3]. Sentharmarai used ceramic waste as a coarse aggregate to make concrete. The test results showed that recycled concrete had good workability and a small difference in mechanical properties with ordinary concrete [4]. Higashiyama used ceramic waste as fine aggregate to make cement mortar. The test results showed that the ability of the recycled cement mortar to inhibit chloride ion is significantly improved [5]. Cheng Yunhong used ceramic recycled aggregate to replace natural or coarse aggregates to prepare concrete. The test results showed that the frost resistance of recycled concrete is not significantly different from ordinary concrete [6]. Qiao Hongxia replaced natural aggregate with ceramic recycled aggregate in proportion to study the performance change of recycled concrete at high temperature, the test results showed that the fire resistance of recycled concrete was stronger than that of ordinary concrete. When the content of ceramic particles was 30%, the resistance to high-temperature damage of recycled concrete was the best [7].

The pores in the concrete provide channels for the entry of moisture and harmful media, which will significantly reduce the thermal insulation performance and durability of the material, and even damage the structure of the material. Therefore, improving the waterproof performance of concrete and inhibiting the entry of moisture and harmful media can improve the performance and durability of concrete. Silicone waterproofing agent has good adhesion, hydrophobicity, and air permeability, which can effectively avoid water absorption of building materials. At the same time, the addition of silicone waterproofing agents can greatly improve the impermeability of concrete components. As a new type of high-efficiency waterproof material with no pollution and no irritation, the current application of silicone waterproofing agents is more widely.

In this paper, the ceramic waste were crushed and sieved to replace partially the sand to prepare cement mortar as aggregate, and different quality of silicone waterproofing agents were added to study the effects on the mechanical properties and water absorption under natural curing conditions, which provide a technical reference for the practical application of silicone modified ceramic recycled aggregate cement mortar.

2. Experimental

2.1. Raw materials
Sand: Natural river sand with a water content of 2.8%. The particle size distribution of 500g sand is shown in Table 1.

| Screen size (mm) | Screening stock (g) | Sieve percentage % | Cumulative screening percentage % |
|-----------------|---------------------|--------------------|----------------------------------|
| 4.75            | 13.82               | 2.76               | 2.76                             |
| 2.36            | 119.57              | 23.91              | 26.67                            |
| 1.18            | 110.74              | 22.15              | 48.82                            |
| 0.60            | 117.60              | 23.52              | 81.34                            |
| 0.30            | 67.60               | 13.52              | 94.86                            |
| 0.15            | 51.57               | 10.31              | 105.17                           |

\[
M_x = \frac{(A_2 + A_4 + A_6 + A_8) - 5A_1}{100 - A_1} = \frac{26.67 + 48.82 + 81.34 + 94.86 + 105.17 - 5 \times 2.67}{100 - 2.76} = 3.53
\]

This natural river sand is coarse sand.

Cement: P.O42.5R cement produced by Huaxin Cement Chongqing Fuling Co., Ltd.

Ceramic Recycled Aggregate: The ceramic waste produced by Mona Lisa Co., Ltd., the particle size distribution is shown in Table 2.
Table 2. Particle size distribution of ceramic recycled aggregate.

| Screen size (mm) | Sieve percentage % | Cumulative screening percentage % |
|-----------------|--------------------|----------------------------------|
| 4.75            | 2.90               | 2.90                             |
| 2.36            | 24.16              | 27.06                            |
| 1.18            | 21.64              | 48.70                            |
| 0.60            | 23.87              | 72.57                            |
| 0.30            | 16.73              | 89.30                            |
| 0.15            | 10.7               | 100.00                           |

The fineness of this ceramic recycled aggregate is close to that of natural river sand.

Waterproofing agent: Dow Corning SHP60 silicone waterproofing agent.

2.2. Preparation and characterization

40 × 40 × 160mm blank cement mortar samples with water-cement ratios of 0.45, 0.50, and 0.55 were prepared, and flexural and compressive strength were tested after 7 days of natural curing to determine the water-cement ratio. After that, 5%, 10%, and 15% ceramic recycled aggregates were added to prepare test pieces, and the flexural and compressive strength were tested after 7 days of curing to determine the amount of ceramic recycled aggregates added. Finally, silicone waterproofing agent samples with cement content of 1%, 2% and 3% were prepared respectively. The samples were cured for 7 and 28 days under natural conditions, and their flexural strength, compressive strength and water absorption were tested. The influence of silicone waterproofing agent on the mechanical properties and water absorption of ceramic recycled aggregate cement mortar was analyzed.

3. Text results and analysis

3.1. Water-cement ratio

Blank samples were prepared with water-cement ratios of 0.45, 0.50 and 0.55. The 7-day flexural strength and compressive strength after natural curing are shown in Table 3.

Table 3. Mechanical properties of different water-cement ratio.

| Water cement ratio | Flexural strength /MPa | Compressive strength /MPa |
|--------------------|------------------------|---------------------------|
| 0.45               | 7.33                   | 33.31                     |
| 0.50               | 7.21                   | 32.55                     |
| 0.55               | 6.25                   | 30.04                     |

As can be seen in the Table 3, the strength of the samples with a water-cement ratio of 0.55 was lower than 0.50 and 0.45, but the workability of cement mortar was not good when it is 0.45, so the water-cement ratio of 0.5 was adopted in this experiment.

3.2. Addition of ceramic recycled aggregate

Under the condition that the water-cement ratio was 0.50, 5%, 10% and 15% of ceramic recycled aggregate were added respectively to prepare the samples. The 7-day flexural strength and compressive strength after natural curing were shown in table 4.
Table 4. Mechanical properties data of ceramic recycled aggregate addition ratio were determined.

| Ceramic recycled aggregate addition | Flexural strength /MPa | Compressive strength /MPa |
|-------------------------------------|------------------------|---------------------------|
| 5%                                  | 6.46                   | 31.28                     |
| 10%                                 | 6.77                   | 32.69                     |
| 15%                                 | 6.07                   | 26.69                     |

As can be seen in the Table 4, when the additional of ceramic recycled ceramic aggregate is 10%, the flexural strength and compressive strength were higher than those of 5% and 15%. Therefore, 10% of ceramic recycled aggregate were used in this experiment.

The blank sample, the blank sample with 10% ceramic recycled aggregate, and the sample with 10% ceramic recycled aggregate modified by are marked as K, TK, TG, which formula are shown in Table 5.

Table 5. Formula of cement mortar

| Sample | Organosilicon waterproofing agent/g | Ceramic aggregate/g | Cement/g | Sand/g | Water/g |
|--------|-------------------------------------|---------------------|----------|--------|---------|
| K      | -                                   | -                   | 450      | 1350   | 202.5   |
| TK     | -                                   | 135                 | 450      | 1215   | 202.5   |
| TG1    | 4.5                                 | 135                 | 450      | 1215   | 202.5   |
| TG2    | 9                                   | 135                 | 450      | 1215   | 202.5   |
| TG3    | 13.5                                | 135                 | 450      | 1215   | 202.5   |

3.3. Mechanical properties

Figure 1 and Figure 2 respectively show the flexural strength and compressive strength of the samples after 7 and 28 days of natural curing.

As can be seen from Figure 1, when the curing time was 7 days, the flexural strength of the sample TK was lower than that of the sample K, but when the curing time was 28 days, the flexural strength of the sample TK increased faster than that of the sample K, indicating that with the increase of curing time, the hydration effect of ceramic recycled aggregate mortar was better. With the addition of silicone waterproofing agent, the flexural strength of the samples decreased gradually. After curing of 28 days, the flexural strength of TG2, TG3, and TG1 decreased by 10.12%, 20.24%, and 7.10% respectively, compared with that of the sample TK.
As can be seen from Figure 2, the compressive strength of the sample TK was lower than that of the sample K. When the curing time was 7 days and 28 days, the compressive strength of the sample was lower by 0.7MPa and 1.4MPa than that of the sample K, with no significant difference. With the addition of silicone waterproofing agent, the compressive strength of the samples decreased more obviously. The compressive strength of TG2, TG3, and TG1 was 7.56%, 17.71%, and 3.46% lower than that of the TK group, respectively. This indicates that with the increase of organosilicon, the waterproof effect of the sample is enhanced, and the hydration of cement mortar is blocked, resulting in a decreasing trend of its strength.

3.4. Water absorption
Figure 3 shows the water absorption of the samples after 7 days and 28 days of natural curing.
As can be seen from Figure 3, the water absorption of the samples all decreased. The reason is that with the increasing of time, the hydration of cement mortar became more sufficient, and the hydration products of C-S-H became denser, resulting in a decrease of porosity. The addition of organosilicon waterproofing agent on the water absorption is relatively obvious, with the increasing of organosilicon, the water absorption of the sample TG decreased first and then increased. When the addition of organosilicon waterproofing agent was 2%, the water absorption of the sample was 4.66%, which was 1.67% lower than that of the sample without the waterproofing agent, this is because the formation of hydrophobic membrane inside the sample by organosilicon waterproof agent, which can inhibit the permeation of water and reduce the water absorption. However, the waterproof agent is not the more the better, but there is an optimal dosage. When the amount of waterproof agent is 3%, the water absorption increases. This is because the excessive waterproof agent inhibits the hydration reaction, causing the structure of the sample to become loose, the porosity to rise and the waterproof performance to decline.

4. Conclusion
After 28 days of natural curing, the mechanical properties and waterproof properties of recycled ceramic aggregate cement mortar were not significantly different from that of ordinary cement mortar: the flexural strength increased by 1.18%, the compressive strength reduced by 2.94%, and the water absorption reduced by 0.5%.

Organosilicon waterproof agent forms hydrophobic film inside the cement sand sample to inhibit water permeation, which can effectively improve the waterproof performance of the sample, but also inhibit the hydration reaction of the sample, resulting in the loose structure of the sample.

With the increase of silicone waterproofing agent, the compressive and flexural strength of the sample gradually decreased, and the water absorption first decreased and then increased. When the amount of waterproof agent was 2%, the comprehensive performance of the sample was the best: the flexural strength was 6.84MPa, the compressive strength was 42.8MPa, and the water absorption was 4.66%.

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