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Preparation of Ultra-High Performance Concrete Material and Its Application in Prefabricated Buildings Based on CAD

Jianmei Huo

Shanxi Vocational College of Tourism, Taiyuan, Shanxi 030031, China, jianmeiHuo@163.com

Corresponding author: Jianmei Huo, jianmeiHuo@163.com

Abstract. In order to effectively reduce production costs, promote the application of ultra-high performance concrete materials, and reduce the pollution of solid waste, the author proposes the preparation of ultra-high performance concrete materials and its application in CAD-based prefabricated buildings. Ultra-high performance concrete (UHPC) is prepared by using crushed and screened waste stone chips instead of quartz sand as aggregate and applied in prefabricated buildings using CAD. Based on the single factor analysis test, the influence of various factors (water cement ratio, cement aggregate ratio, water reducer content, steel fiber content) on the compressive strength, flexural strength and fluidity of stone chips UHPC was studied. The results show that when the cement-aggregate ratio, water-cement ratio, water-reducing agent content and steel fiber content are 0.63, 0.2, 2.1% and 1.5% respectively, the mechanical properties and working properties of UHPC are the best, the maximum 7d compressive strength is 113.7MPa, and the bending strength is 35.2MPa; By analyzing the stress-strain curve, it is found that adding steel fiber can not only improve the mechanical strength of UHPC, but also significantly improve the toughness and residual compressive strength of UHPC. Conclusion: The test system analyzes the influence of different factors on mechanical strength and working performance, and obtains the best mixing amount of each component.

Keywords: Ultra-high-performance concrete; Stone chips; Mechanical strength; Mobility; Prefabricated building; CAD.
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1 INTRODUCTION

The contradiction between the requirements of urban high reliability operation and the extremely fragile environment has increasingly become a major difficulty in human society, and the engineering construction will undoubtedly make this contradiction more prominent [1]. Concrete plays a vital role in the reliability and safety of buildings, it is the most widely used material in the main body of the project, which determines and also affects the harmonious relationship between human and nature. Ordinary concrete has many problems, such as low rigidity, heavy self-weight, insufficient durability and poor crack resistance. This makes the use of materials inadequate and the safety of buildings inadequate. In addition, the random emission of powder dust and harmful gases also aggravates the environmental pollution.

With the continuous improvement of people's requirements for modern and future building standards, how to make the limited materials play a more valuable role and how to make the materials have a longer service life has attracted extensive attention of scholars. Ultra-high performance concrete has been well explored and further studied, and has become an important direction of the development of modern cement-based composites. Figure 1 shows the preparation of ultra-high performance concrete material [2].

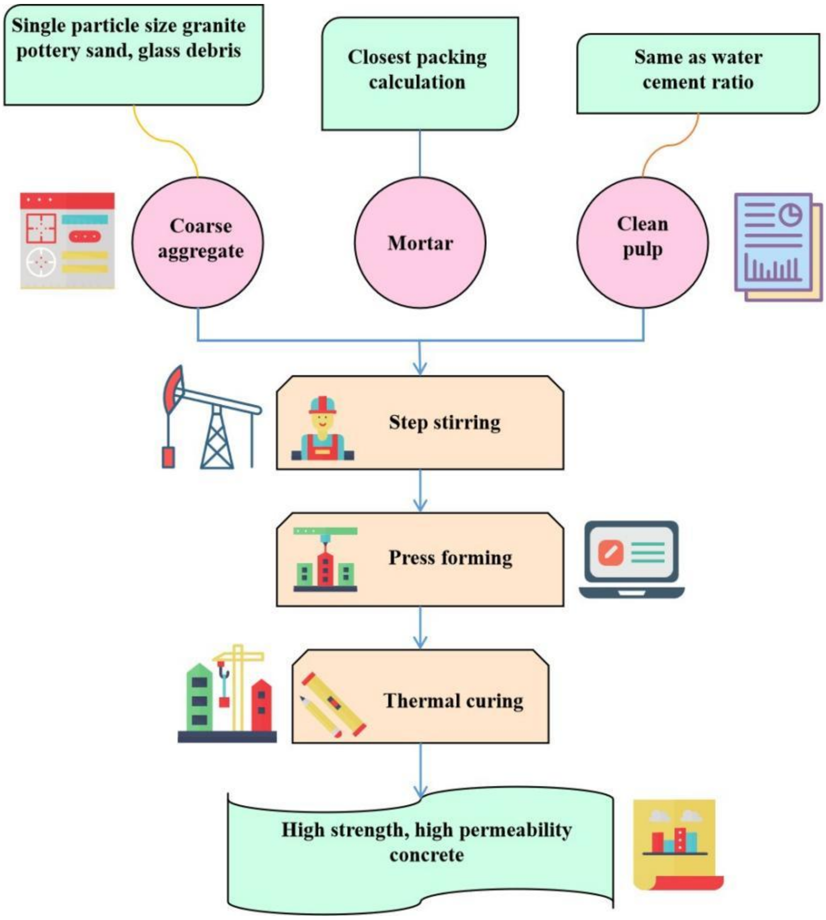

Figure 1: Preparation of ultra-high performance concrete materials.

2 LITERATURE REVIEW

In recent years, many scholars at home and abroad have also done a lot of research on UHPC and achieved fruitful results.

UHPC is the most innovative cement-based engineering material in the past 30 years; it not only has the easy construction performance of ordinary concrete, but also has the ability of self-compacting and normal temperature curing. Compared with common cement-based concrete materials, it has more superior performance in compression strength, tensile strength, abrasion resistance, corrosion resistance, toughness, crack resistance, frost resistance and permeability resistance, and has many advantages applicable to the field of building skin design, which has important application value for assembled building skin [3].

Stone chips are the waste produced in the process of building stone manufacturing, every 10t of stone processed will produce about 3t of stone chip waste. The stacking of waste rock debris takes up a lot of land resources and seriously damages the surrounding ecosystem. In recent years, with the gradual improvement of solid waste utilization technology and the awareness of ecological environment protection, the preparation of concrete from stone chips has become a research hotspot. At present, the application of stone chips in concrete is still confined to ordinary concrete, and the utilization rate of stone chip waste is not high, no research on the application of stone chips in the preparation of UHPC has been found.

The use of stone chips instead of quartz sand to prepare UHPC will effectively reduce the production cost, contribute to the promotion and application of UHPC, and also "turn waste into material" to reduce the pollution of solid waste. Based on the classification of UHPC, the author analyzes the application prospect of UHPC in the field of prefabricated building, with a view to promoting the application of UHPC in the field of prefabricated building, and uses stone chips as aggregate to completely replace quartz sand to prepare UHPC, the effects of different factors on mechanical strength and working performance were systematically analyzed through the test, and the optimum mixing amount of each component was obtained, the UHPC was applied to the prefabricated building based on CAD.

3 RESEARCH METHODS

3.1 UHPC Classification

Based on the analysis of UHPC application status, the main application engineering categories and facilities of UHPC are as follows:

3.1.1 Bridge works, including cast-in-place bridge deck pavement, bridge wet joints, precast bridge deck slab, bridge deck pavement, precast box girder;

3.1.2 Building works, including the exterior wall decorative panels, small prefabricated components (stairs, balconies), and prefabricated component node connections;

3.1.3 Municipal engineering, including prefabricated cover plate, prefabricated integrated pipe gallery, infrastructure structure reinforcement, etc. [4].

3.2 Application of UHPC in Prefabricated Buildings

3.2.1 Exterior wall decoration

UHPC is one of the most important and extensive application fields of UHPC for building exterior wall decoration, including hollow curtain wall, sunshade, sandwich insulation wall panel, dry-hanging or wet-laying decorative panel, etc. UHPC has super-high strength, super-high toughness and super-high durability, which makes it meet the requirement of structure capability, reduce the cross-section size of structure, and realize light weight and thin-wall, so that architects can break through the constraints of materials and design a lightweight and beautiful structure shape.

Take the European and Mediterranean Cultural Museum (MuCEM) in Marseille Saint-Jean, France, as an example, its hollow enclosure curtain wall is built by UHPC and is beautifully made. The exquisite and gorgeous patterns reflect the long tradition of Mediterranean culture and handicrafts, and also highlight the superior comprehensive performance and huge application potential of ultra-high-performance materials in the field of architectural decoration.

Although the exterior wall decoration UHPC is currently more used in landmark and creative buildings to reflect its artistic value, it can also industrialize the production of various types of

UHPC standard panels in the future, expand its application in prefabricated buildings, and give play to the advantages of UHPC lightweight and good durability [5].

3.2.2 Assembled slurry anchor lap

For prefabricated concrete structures, the core is reliable reinforcement connection technology. At present, in addition to the reinforcement sleeve grouting connection, the wet joint connection is also widely used, and the slurry anchor lap joint is a kind of wet joint connection, and the slurry anchor lap joint refers to the reserved holes in the prefabricated concrete components, the overlapping method of inserting reinforcement to be overlapped in the duct and pouring cement-based materials for anchoring.

Due to the limitation of the strength of the anchorage material and the insufficient grip force between the reinforcement and the traditional reinforcement mortar anchor lap connection, the reinforcement lap is too long in the design process, and the problem of insufficient filling is easy to occur in the construction process, which brings huge risks to the safety of the fabricated concrete structure. UHPC has ultra-high compressive strength (usually ≥ 120MPa).

In fact, UHPC wet joint connection members have been successfully applied in prefabricated bridge engineering for the first time, such as the joint connection between beam-beam, cap beam-pier column and pile-cap of prefabricated structure of Shanghai Jiamin Elevated Bridge, and the longitudinal joint connection between Ningbo Airport Road Nanyan Municipal Road and the integrated elevated box girder of light rail. The successful application of the technical system of the combination of prefabricated bridges and UHPC wet joints provides a basis for the research of UHPC application technology in the field of prefabricated grout-anchor bonding.

A company in Shanghai took the lead in carrying out the technical research of UHPC used for the connection of prefabricated building grout anchors in China. Through a large number of tests, it is demonstrated that when the overlapping length of reinforcement is 10d, the prefabricated beam joints, column joints and beam-column joints can be cast in place, and part of the performance is better than cast-in-place, effectively shortening the overlapping length of reinforcement and reducing the construction difficulty [6].

3.2.3 Fabricated prefabricated components

Some landmark buildings abroad have also explored the application of UHPC prefabricated structural columns and structural beams, for example, in MuCEM European Mediterranean Museum, a large number of UHPC columns are used as structural supports, the columns adopt three forms: Vertical column, Y-shaped column, N-shaped column. The diameter (25-40cm) and height (2.89-8.79m) of the column are different, and 80 different combinations are finally formed. However, the cost of UHPC prefabricated structural columns in prefabricated buildings is still too high[7-8].

3.3 Raw Materials

3.3.1 Granite stone chips:

Taken from the waste leftover materials in the quarry, crushed and screened by 0.25 and 2mm respectively, the particles with the particle size of 0.25~2mm and 0~0.25mm are mixed according to the maximum bulk density and used as aggregates, the mixing ratio in this test is 3:1. The performance parameters of blended stone chips are shown in Table 1.

Apparent density/(kg·m-3)	*Bulk density/(kg·m-3)*	*Accumulative porosity/%*	*Fineness modulus*
2361	1559	34	2.16

Table 1: Performance index of stone chips.

3.3.2 Cement:

Jidong brand P.O42.5 ordinary Portland cement is used.

3.3.3 Silica fume:

The average particle size is 0.2 μ m, silica fume with a specific surface area of 20m2/g.

3.3.4 Fly ash:

Class I fly ash with a specific surface area of 6000cm2/g.

3.3.5 Water-reducing agent:

Polycarboxylic acid high-efficient water-reducing agent is used, and its water-reducing rate is not less than 35%.

3.3.6 Steel fiber:

Copper plated steel fiber with diameter of 0.2mm, length of 13mm and tensile strength of more than 2850MPa.

3.4 Test Scheme Design

The influence of cement-aggregate ratio, water-cement ratio, water-reducing agent content and steel fiber content on the properties of stone chip UHPC was studied by single factor analysis test. The change of mechanical properties of UHPC with a cement-aggregate ratio of 0.6~0.8 has been studied, it is found that the mechanical strength is the best when the cement-aggregate ratio is 0.6, in view of this, the research range of the cement-aggregate ratio of stone chips UHPC designed for this test is 0.5~0.83; The water-binder ratio of UHPC is low, generally between 0.16 and 0.2, considering the high water absorption of stone chips, the design range of the water-binder ratio of stone chips UHPC is 0.18 to 0.22; The content of polycarboxylic acid super plasticizer in UHPC is generally about 2% of the mass of cementitious materials, so the research range of the designed content of super plasticizer is 1.8%~2.2%.

Steel fiber is one of the important influencing factors to improve the toughness of UHPC, the maximum content of steel fiber in UHPC can reach more than 200kg/m3, but too high content of steel fiber will affect the working performance of fresh concrete and greatly increase the cost, therefore, the variation range of the steel fiber content of UHPC stone chips in the test design is 0~160kg/m3 (the corresponding volume content is about 0%~2.0%). Divide the range of four influencing factors into five equal parts, take the middle value of each factor as the benchmark mix ratio, and carry out single factor analysis test on the basis of the benchmark mix ratio. The ternary cementations system of cement, fly ash and silica fume is adopted, and the mass ratio of each component is 3:2:1 [9-10].

3.5 Test Piece Preparation and Curing Conditions

Weigh the material according to the proportion, add steel fiber to continue mixing after dry mixing, then add water reducer and water, and use the cement mortar mixer to mix for 5min before discharging and vibrating. The mold test specification is 40mm × 40mm × 160mm, demoulding after 24h. The author has designed four ways to maintain health: 1) 7d standard curing (curing box 20, relative humidity greater than 95%); 2) 3 d water bath curing (water bath 90)+4 d standard curing; 3) 3 d dry heat curing (thermostat 150)+4 d standard curing; 4) 1.5d water bath curing+1.5d dry heat curing+4d standard curing.

3.6 Test Contents and Methods

The unconfined compressive strength test and three-point bending strength test shall be conducted. Use the universal testing machine with the model of SHT4605 for mechanical test. The loading speed of compression test is 1.2 MPa/s, and that of bending test is 0.08 MPa/s [11].

4 RESULT ANALYSIS

4.1 Single Factor Analysis Test

The test results of UHPC flow ability and 7d mechanical strength of stone chips with different proportions are shown in Table 2, among them, the proportion of test pieces numbered A3, B3, C3 and D3 is the same, which is the benchmark proportion, there are 17 groups of test pieces in total, and the mechanical strength is the average of the test results of the three test pieces.

number	*Water-binder ratio/ %*	*Cementitious ratio/%*	*Water reducing agent/ %*	*Steel fiber/ %*	*Flexural strength/MPa*	*Compressive strength/MPa*	*Mobility/mm*
A1	0.18	0.63	2.0	1.5	35.22	82.35	131.0
A2	0.19	0.63	2.0	1.5	25.16	79.55	174.0
A3	0.20	0.63	2.0	1.5	27.45	81.06	203.0
A4	0.21	0.63	2.0	1.5	18.76	72.54	252.0
A5	0.22	0.63	2.0	1.5	21.07	68.16	261.7
B1	0.20	0.83	2.0	1.5	26.27	68.17	252.7
B2	0.20	0.71	2.0	1.5	23.29	72.8	220.3
B3	0.20	0.63	2.0	1.5	27.44	81.06	203.0
B4	0.20	0.56	2.0	1.5	30.76	81.64	172.3
B5	0.20	0.5	2.0	1.5	29.38	78.39	159.7
C1	0.20	0.63	1.8	1.5	25.12	77.52	197.0
C2	0.20	0.63	1.9	1.5	25.34	70.81	201.6
C3	0.20	0.63	2.0	1.5	27.44	81.05	203.0
C4	0.20	0.63	2.1	1.5	28.64	78.01	213.4
C5	0.20	0.63	2.2	1.5	23.49	74.65	224.0
D1	0.20	0.63	2.0	0.0	16.42	55.59	233.3
D2	0.20	0.63	2.0	0.5	17.04	66.00	227.7
D3	0.20	0.63	2.0	1.0	18.96	74.27	215.7
D4	0.20	0.63	2.0	1.5	27.44	81.05	203.0
D5	0.20	0.63	2.0	2.0	26.92	79.72	197.7

Table 2: UHPC mix proportion and test results.

4.1.1 Effect of water-binder ratio on UHPC performance

The relationship between water-binder ratio and UHPC performance is shown in Figure 2. As can be seen from Figure 2, with the increase of water-cement ratio, the total mechanical strength gradually decreased and the fluidity gradually increased. When the water-binder ratio is 0.18, the compressive strength and bending strength reach 82.35% and 35.22 MPa respectively, and the fluidity is only 131 mm.

In the meantime, the mechanical strength of the test paper is the highest, but the manufacturing difficulty is big, and the process performance is poor. When the water-binder ratio is 0.22, the compressive strength is 68.16 MPa, the flexural strength is 21.07 MPa, and the fluidity is 262 mm. respectively. It is compared with the specimens with the ratio of water-binder at 0.18, the compressive strength and flexural strength decreased by 17.2% and 40.2%, respectively, but the fluidity is increased by one time. The 28 - day compressive strength of rock chips UHPC is similar to that of 7d compressive strength. When water-cement ratio is 0.18, the compressive strength is the highest, reaching 106.3MPa, which is about 30% higher than 7d compressive strength. Considering the working principle and mechanics, it is advisable to select 0.2% water-binder ratio in engineering application [12].

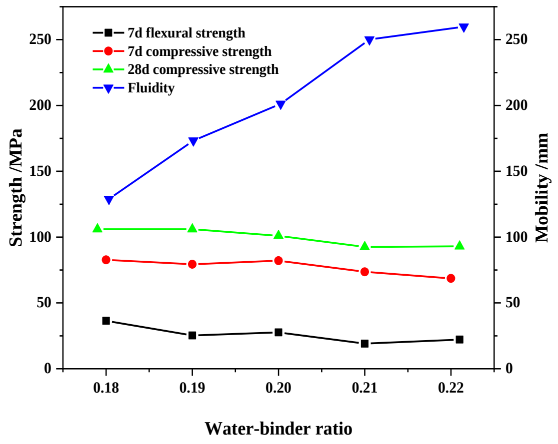

Figure 2: Effect of water-cement ratio on mechanical strength of UHPC.

4.1.2 Effect of cement-aggregate ratio on UHPC performance

Mechanical properties and test results of UHPC with different surface textures are shown in Figure 3. As can be seen from Figure3, when the cement-aggregate ratio increases from 0.5 to 0.83, the mechanical strength of the specimen first increases and then decreases, and the fluidity gradually increases. When the cement-aggregate ratio is 0.56, the mechanical strength is the highest, the compressive strength is 81.64MPa, and bending strength is 30.76MPa.

With the increase of the cement-aggregate ratio, the fluidity decreases significantly, this is because the aggregate contains stone powder with high water absorption, when the content of stone powder increases, part of the free water in the mixture is absorbed by the stone powder, and the fluidity performance is weakened. When the cement-aggregate ratio increases from 0.56 to 0.63, the mechanical strength of the test piece increases slightly, but the fluidity increases from 172mm to 203mm, and the working performance is significantly improved. Therefore, it is recommended to select a cement-aggregate ratio of 0.63 in practical engineering applications [13].

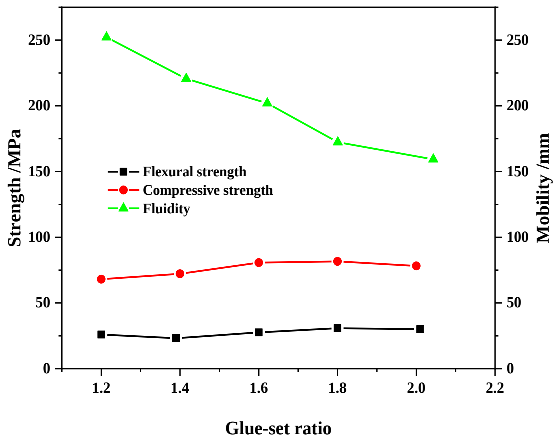

Figure 3: Effect of cement-aggregate ratio on mechanical strength of UHPC.

4.1.3 Effect of water reducer dosage on UHPC performance

The relationship between the amount of water reducer and the performance of UHPC is shown in Figure 4. It can be seen from Figure 4 that the amount of water reducer has a small impact on mechanical strength, but a significant impact on fluidity. The amount of water reducer is gradually increased from 1.8% to 2.2%, the fluidity increases by 2.3%, 3.0%, 8.3% and 13.7%, respectively. When the dosage of water reducer reaches 2.1% and 2.2%, the fluidity increases greatly, and when the dosage reaches 2.2%, the mechanical strength decreases, it is suggested that the dosage of water reducer should be controlled below 2.2% in engineering application [14].

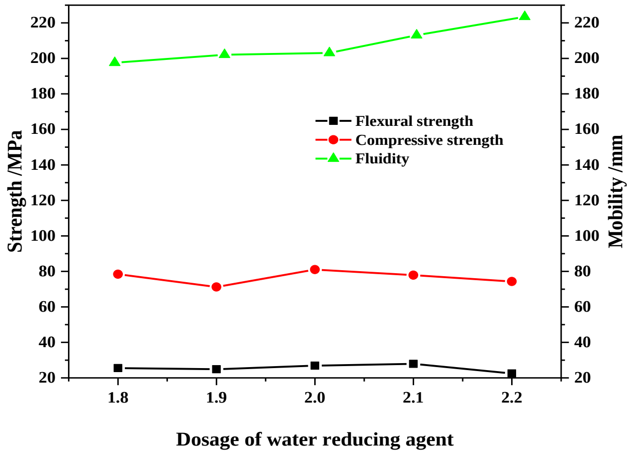

Figure 4: Effect of water reducer dosage on UHPC performance.

4.1.4 Effect of steel fiber on UHPC performance

The relationship between steel fiber content and UHPC performance is shown in Figure. 5. It can be seen from Figure 5 that with the increase of fiber content, the mechanical strength gradually increases and the fluidity gradually decreases. Compared with the non-fiber structure, when the fiber content is 0.5%, 1%, 1.5% and 2%, the bending strength of the steel fiber is increased by 3.8%, 15.4%, 67.1% and 63.9% respectively, and the compressive strength is increased by 18.7%, 33.6%, 45.8% and 43.4% respectively. The fluidity decreases with the increase of steel fiber content, because the pillar formed by a large number of steel fibers affects the fluidity of concrete mixture, and the fluidity decreases. When the steel fiber content is 1.5%, the mechanical strength is the highest, and the compressive strength and bending strength are 81.05% and 27.44 MPa, respectively. and so on. In applied engineering, it is recommended to select 1.5% of the volume of steel fiber [15].

4.2 Stress-strain Curve Analysis

The compressive stress-strain curves of UHPC specimens with different cementations ratios are shown in Figure 6. The curve includes three stages: 1) Elastic deformation stage: When the initial stress is applied to the specimen to produce cracks, the specimen undergoes elastic deformation at this stage, and the curve is approximately straight; 2) Crack development stage: Micro cracks appear in the specimen and slowly extend and expand, the curve slope decreases, and the stress slowly increases to the maximum value; 3) Failure stage: When the stress reaches the maximum, the specimen is damaged. With the increase of strain, the stress gradually decreases, and the crack gradually penetrates the whole specimen. In addition, the formula for calculating the compressive strength of concrete cube is (1)

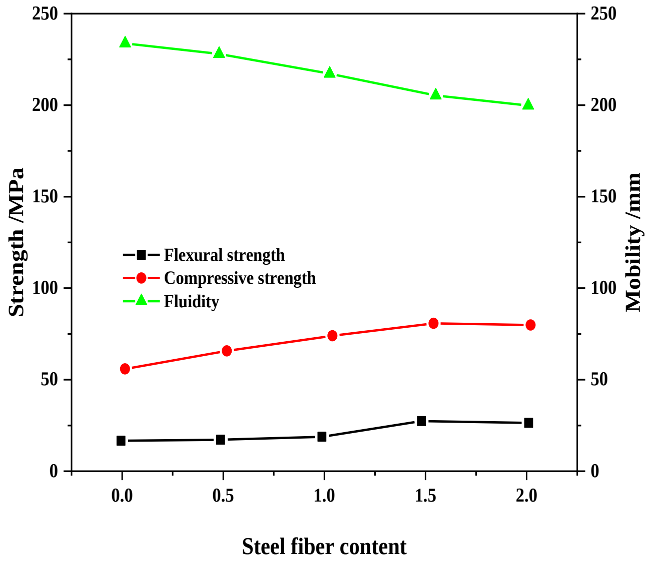

Figure 5: Effect of steel fiber content on mechanical strength of UHPC.

$$f_{cc} = \frac{F}{A} \tag{4.1}$$

Where, F is the force size and A is the force area.

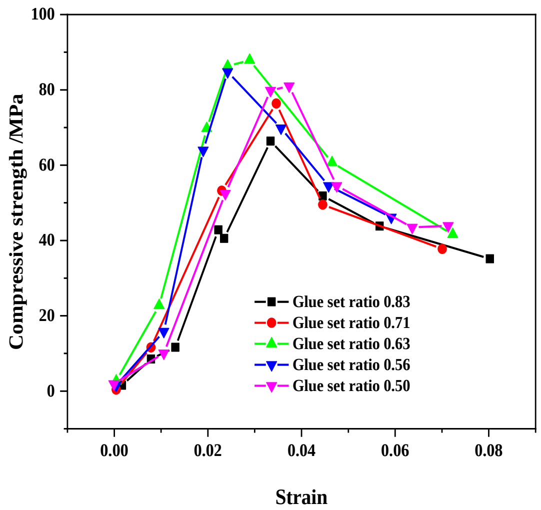

Figure 6: Compressive stress-strain curve of UHPC with different cement-aggregate ratio.

At the stage of curve elastic deformation, when the cement-aggregate ratio increases from 0.50 to 0.83, the slope first increases and then decreases, and the elastic modulus first increases and then decreases, which accords with the law of compressive strength; In the failure stage, the stress in the curve of different rubber spacing gradually reduced to 40MPa, the curve tends to flat, and the stress concentration tends to be stable [16].

The stress concentration characteristics of UHPC with different fiber content are shown in Figure 7 [17-18]. When the load reaches the failure load, the stress of the unbounded fiber reduces rapidly, brittle failure occurs, and the bearing capacity loses; When the load of the composite specimen with steel fiber reaches the highest value, because of the toughness and crack resistance of steel fiber, the stress decreases and there is also some bearing capacity. The residual compressive strength of specimens is proportional to the steel fiber content. The results show that steel fiber can not only improve the compressive strength of UHPC, but also effectively improve the toughness and residual compressive strength of specimens [19].

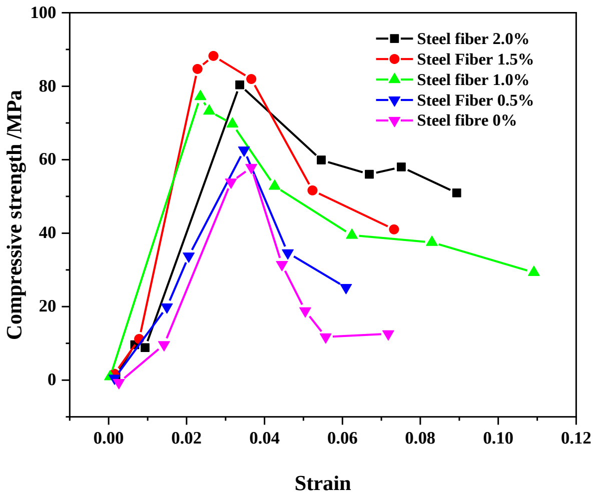

Figure 7: Compressive stress-strain curve of UHPC with different fiber content

5 CONCLUSION

The UHPC is prepared by using stone chip waste as aggregate, the influence of different influencing factors on the properties of UHPC is studied through single factor analysis test, the stress-strain curve of stone chip UHPC is analyzed, and the following conclusions are obtained: The stone chip UHPC with the maximum compressive strength of 113.7MPa and the maximum flexural strength of 35.22MPa was prepared, which proved that the preparation of UHPC from stone chip waste was effective and feasible. Through single factor test, it is found that the best content of each component is when the cement-aggregate ratio is 0.63, the water-cement ratio is 0.2, the volume content of steel fiber is 1.5%, and the water reducer content is 2.1%, at this time, the mechanical strength and working performance of stone chips UHPC are the best. The stress-strain curve analysis shows that the stress-strain curve characteristics of stone chip UHPC are similar to those of traditional UHPC, steel fiber can not only improve the mechanical strength of UHPC, but also effectively improve the toughness and residual compressive strength of UHPC.

Jianmei Huo, https://orcid.org/0009-0009-9633-8316

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