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Experiment Research of Concrete Splitting Tensile Strength Based on Age and Curing Temperature

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Abstract: In order to study the curing ages and aging degree influences on concrete tensile strength, the splitting experiments on 25 groups specimens including 75 cubes were conducted in the paper. The test parameters mainly include strength grade, age and aging degree. The tests showed that the splitting strength increases with the age and it increases rapidly in the first 7 days. The aging degree has a certain effect on the splitting tensile strength of concrete, and the greater difference in aging degree, the greater difference in splitting strength of concrete. The splitting tensile strength predictor formulas which include curing ages and aging degree parameters were obtained by least square method based on the test results.

1.Introduction

With the promotion and application of green buildings and green construction, the aluminum alloy formwork early demolition support system has been used in engineering. In order to shorten the construction period and speed up the use of the formwork, the early demolishing formwork system is used in the engineering projects. So, the concrete structure began to bear the load at about 1.5 days of age. The prediction formulas of various mechanical indexes of early age concrete are key elements for the design of early dismantling formwork support system. At present, some scholars have studied the mechanical properties of early age concrete. The main contents include the mechanical indexes such as the compressive strength of concrete cubes in early age and the compressive strength of prisms under standard curing and natural curing conditions, and the corresponding predictions formulas are proposed [1-4]. However, the most current prediction formulas of the mechanical properties of early age concrete don't consider the influence of concrete curing temperature.

Therefore, three kind of concrete grades C20, C30, and C45 were designed and the splitting tensile strength at various ages of each concrete grades is studied. Based on the analysis of the influence of age and aging degree on the splitting tensile strength at different ages, the prediction formulas for concrete splitting strength of each age based on the dual parameters of age and aging degree was proposed.

2.Test overview

2.1 Test raw materials and mix ratio
The test adopts P.O.42.5 grade ordinary Portland cement; the coarse aggregate is continuous grade and

its size of gravel is about 10~25mm; the fine aggregate is river sand which apparent density and mud content is 2.6kg/m³ and 0.2% and its fineness modulus is 2.7; The water-reducing agent is Fujian Jianke superplasticizer which water reduction rate is 25%-35%; the admixture is Ningde Datang Power Plant II grade fly ash. The concrete mix ratio is shown in Table 1.

Table 1 Concrete mix ratio of each group

concrete grades	Slump /mm	Unit dosage /kg/m³					
		Cement	Water	Sand	Stone	Water reducing agent	Fly ash
C20	160	333	777	1165	233	0.03	37
C30	170	330	726	1088	202	1.55	36.50
C45	145	330	726	1088	181	2.05	36.50

2.2 Test scheme

In order to consider the influence of age and aging degree on the concrete splitting performance of each age, the aging degree is accumulated every day and its unit is °C•d. To study the effects of aging degree, the two series of tests for C20 and C30 were scheduled for mid-September and December. The sample size of the splitting tensile strength test was 150 mm × 150 mm × 150 mm; the ages were considered 1.5d, 3d, 7d, 14d and 28d, respectively.

2.3 Test equipment and method

The concrete cube splitting test refers to GB/T50081-2002 "Standard test method for basic mechanical properties of ordinary concrete", which is loaded by YAW-3000 microcomputer controlled electro-hydraulic servo pressure tester. Figure 1 shows the test conditions during the test.

Figure 1 Cube splitting test

3.Analysis of test results

3.1 Splitting test failure phenomenon

When the age was 1.5d, the test piece between the upper and lower plywood showed obvious indentation when the test piece was destroyed. The concrete between the plywood had the marks of being crushed and sheared, and some of the coarse aggregate also fell off. At the stage of failure, most of the coarse aggregates on the cleft surface were exposed without obvious signs of splitting and breaking. Figures 2(a), (b) and (c) and (d) showed the typical failure modes of the 1.5d specimens of the C20 series and C45 series.

When the age was 3d, the fracture of the cross section of the test block was concentrated in the cement stone matrix part, and the coarse aggregate of the fracture surface had already broken. Fig. 2(e), (f) and (g), (h) were typical failure modes of C30 grade.

When the age was 7~14d, the failure surface gradually transitions from the coarse aggregate cemented surface to the coarse aggregate. When it breaks, there were a slight cracking sound, and the failure process of the test block showed brittle failure.
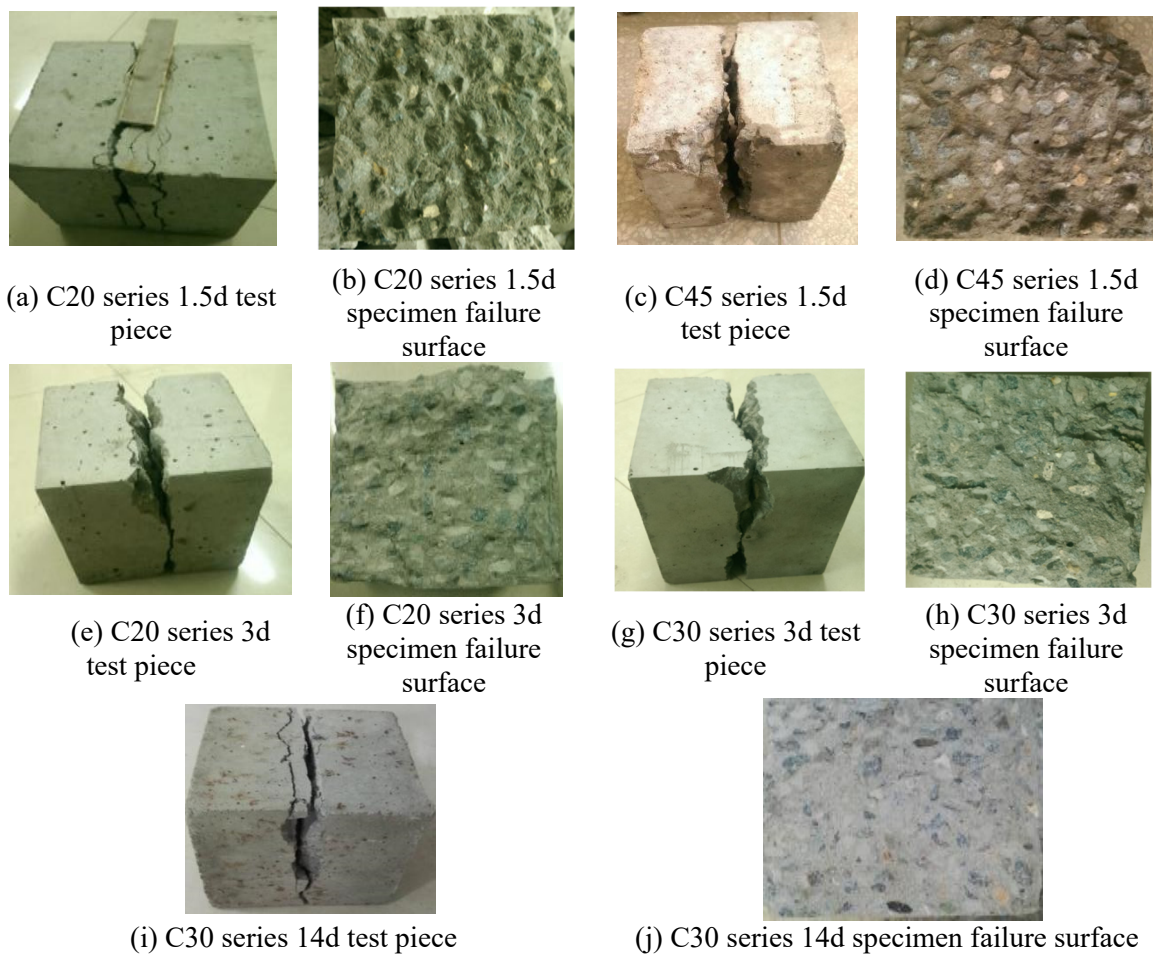
(a) C20 series 1.5d test piece

(b) C20 series 1.5d specimen failure surface

(c) C45 series 1.5d test piece

(d) C45 series 1.5d specimen failure surface

(e) C20 series 3d test piece

(f) C20 series 3d specimen failure surface

(g) C30 series 3d test piece

(h) C30 series 3d specimen failure surface

(i) C30 series 14d test piece

(j) C30 series 14d specimen failure surface

Figure 2 Cubic test block splitting tensile test failure mode

3.2 Splitting strength analysis

Table 2 shows the splitting strength of the C20, C30, and C45 series cubes at 1.5d, 3d, 7d, 14d, and 28d.The AT refers to age degree.

Figure 3 shows the comparison of the splitting strengths of the first and second batches of the C20 and C30 series. The difference aging degree of 1.5 days, 3 days, 7 days, 14 days and 28 days in the two batches of C20 series is -5 °C, -5 °C, 12 °C, 36 °C, 117.5 °C. The difference aging degree of 1.5 days, 3 days, 7 days, 14 days and 28 days in the two batches of C30 series was 24 ° C, 42 ° C, 71.5 ° C, 126.5 ° C, 184 ° C.

Table 2 Average Cubic Splitting Strength of C20, C30, and C45 Series Test Pieces

Age/ d	C20(first batch / second batch)		C30(first batch / second batch)		C45	
	AT/℃•d	f_{cp}/MPa	AT /℃•d	f_{cp}/MPa	AT /℃•d	f_{cp}/MPa
1.5	28/33	0.9/0.9	48.5/24.5	1.4/1	44.5	2.2
3	40.5/45.5	1.2/1.4	75/33	1.7/1.5	67.5	2.5
7	108/96	1.6/1.7	157.5/86	2.3/2	161	2.7
14	211.5/175.5	1.8/2.2	312/185.5	2.5/2.1	321.5	3.2
28	406.50/289	2.2/2.3	568.5/384.5	3.6/2.4	612.5	3.8
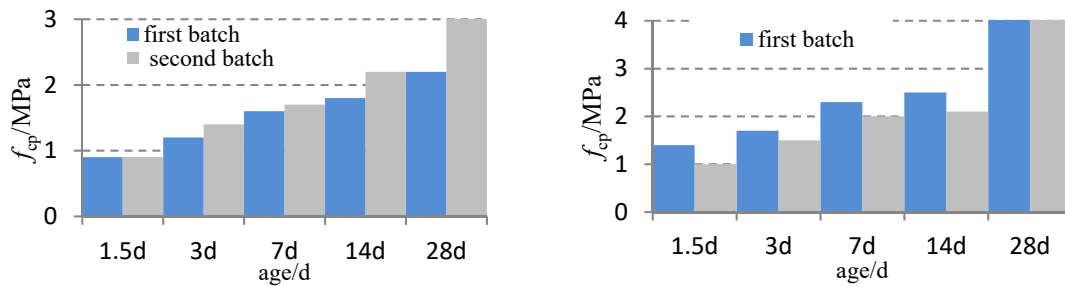
(a) C20 series test piece   (b)   C20 series test piece

Figure 3 Relationship between curing age and concrete cubic compressive strength

It can be seen from Table 2 and Figure 3 that the splitting strength of each set of specimens increases with the increase of age, and the strength of the first 7 days increases rapidly. When the age is 1.5 days old, the splitting strength of first and second batches of the C20 series, the first and second batches of the C30 series, the C45 series reached 40.9%, 39.1%, 38.9% 41.7%, 57.9% of 28d respectively. When the age is 7 days old, the splitting strength of first and second batches of the C20 series, the first and second batches of the C30 series, the C45 series reached 72.7%, 73.9%, 63.8%, 83.3%, 71% of 28d, respectively.

It can also be seen from Table 2 and Figure 3 that the age degree has a certain influence on the splitting strength of concrete. The greater the difference in age degree, the more the difference in concrete splitting strength. The age degree difference of the two batches of C20 is small, the difference of corresponding splitting strength is also small;While the age degree difference of the two batches of C30 is greater, the difference of corresponding splitting strength is also larger. The splitting tensile strength difference of the first and second batches of C20 series at 1.5d, 3d, 7d, 14d and 28d is 0MPa, 0.2MPa, 0.1MPa, 0.4MPa and 0.1MPa respectively, which are 0%, 17.1%, 5.6%,19.3% and 0.3% of the average strength of the two batches respectively. The splitting tensile strength difference of the first and second batches of C30 series at 1.5d, 3d, 7d, 14d and 28d is 0.4MPa, 0.2MPa, 0.3MPa, 0.4MPa and 1.2MPa respectively, which are 34.1%, 13.3%, 23%,18.5% and 41.3% of the average strength of the two batches respectively.

4.Prediction formulas of concrete splitting tensile strength based on two parameters

4.1 Prediction formulas

The splitting tensile strength in Table 2 were compared by analyzing its change law with age and age degree. Using the mathematical model $Y = A f_{cu}(t,T)^B$, the regression calculation of the cubic splitting tensile strength values was carried out, and the prediction formula of the concrete cubic splitting tensile strength of different curing ages and age degree is obtained, such as formula (1).

$$f_{cp}(t,T) = 0.25 \times f_{cu}(t,T)^{0.7} \qquad (1)$$

In the formula (1): The t is the curing age of the specimens (d); the T is age degree of the specimens（℃•d）; the $f_{cu}(t,T)$ is the cubic strength prediction formula based on age and age degree, as shown in formula (2)：

$$f_{cu}(t,T) = [0.2134 \times \ln(t) + 0.3122]$$
$$\times [1 + 0.05968 \times (1 - \frac{20 \times t}{T})] f_{cu} \qquad (2)$$

In the formula(2): f_{cu} is the 28-day cube compressive strength . The results calculated by formula (1) and formula (2)   are compared with the data in Table 2, and the agreement is better, as shown in Figure 4.
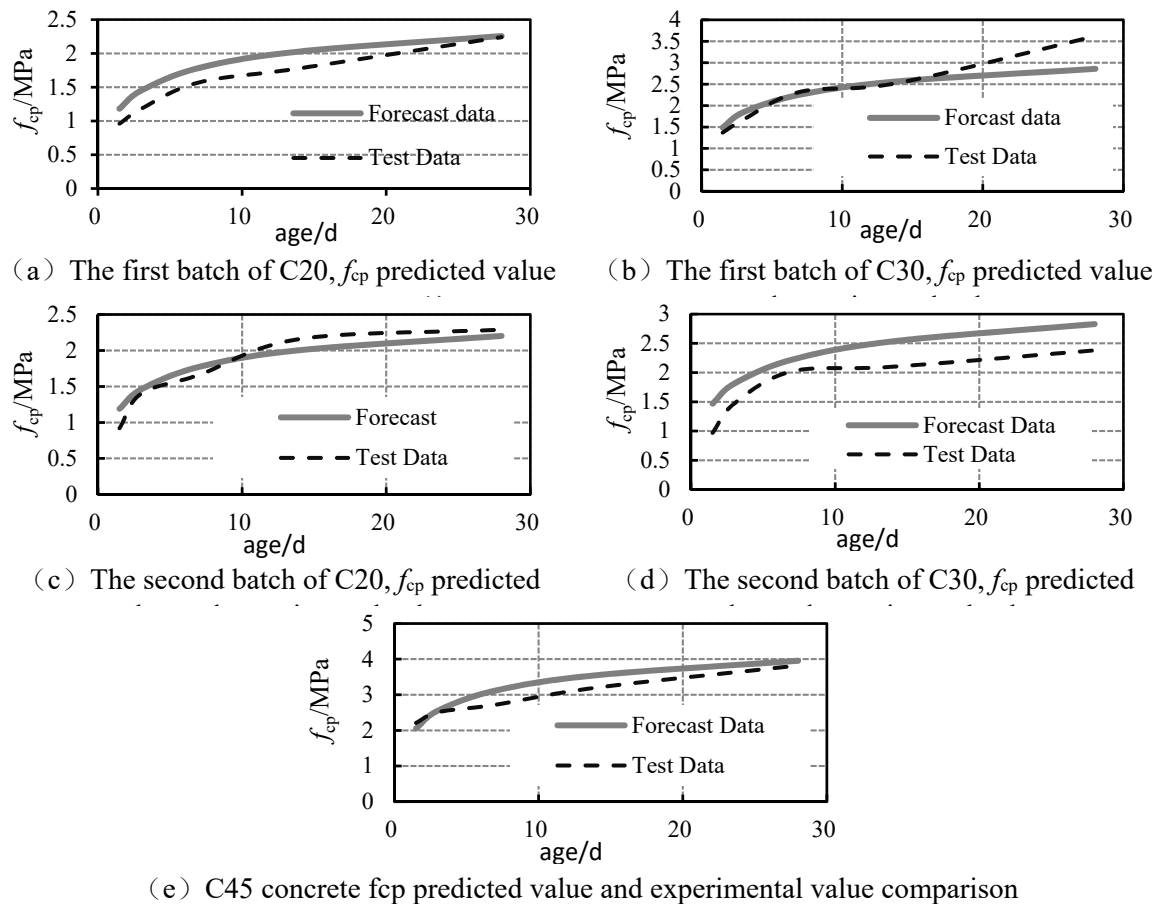
（a）The first batch of C20, f_{cp} predicted value

（b）The first batch of C30, f_{cp} predicted value

（c）The second batch of C20, f_{cp} predicted

（d）The second batch of C30, f_{cp} predicted

（e）C45 concrete fcp predicted value and experimental value comparison

Fig. 4 Comparison of predicted values of concrete splitting tensile strength and experimental values

4.2 Predictive formulas accuracy verification

In order to ensure the accuracy of the prediction formula (1), the intensity values obtained by the prediction formula (1) under the corresponding conditions are compared with the C40 concrete splitting tensile strength value f_{cp} in the papers of Wang Mengmeng and other related papers [4]. The results are shown in Table 3 and Figure 4.

It can also be seen from Fig.5 that when the concrete curing time exceeds one day, the predicted intensity value of formula (1) and the relevant data in the literature reduced to less than 0.2 MPa, and the later phase difference is even about 0.1 MPa. It can be seen that the intensity curve of the prediction formulas is consistent with the rule of the experimental data [4] and the difference is small.

Table 3   The splitting tensile strength comparison between Literature [4] and prediction formula (1)

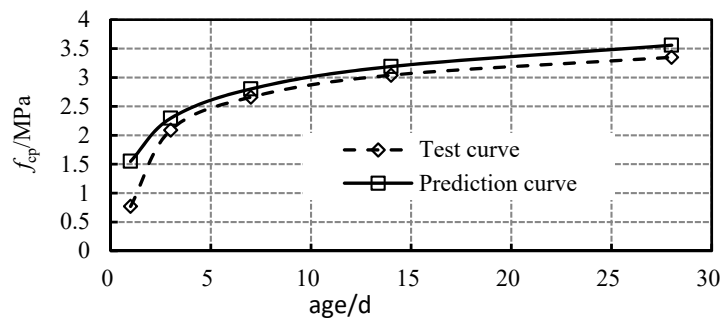| Age/d	AT/℃·d	Test value /MPa	Predictive value /MPa	Difference /MPa
1	20	0.8	1.6	0.8
3	60	2.1	2.3	0.2
7	140	2.7	2.8	0.1
14	280	3.0	3.2	0.1
28	560	3.4	3.6	0.2

Figure 5. Literature [4] C40 concrete f_{cp} test value curve and predicted value curve comparison

5. Conclusion
(1) The splitting strength of each group of specimens increased with the increase of age, and the intensity of the first 7 days increased rapidly, generally reaching about 70% of the intensity of 28 days.

(2) The age degree has a certain influence on the splitting strength of concrete. The age degree difference is larger, splitting strength difference is larger.

(3) Based on age and age degress, the prediction formulas of splitting strength of each age are proposed, which can provide reference for engineering application.

Acknowledgments

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