Advanced Materials Research *Online: 2013-03-11*
ISSN: 1662-8985, Vols. 671-674, pp 1918-1922
doi:10.4028/www.scientific.net/AMR.671-674.1918

Research on the Strength of High-strength Steel Slag Concrete with Skeleton Coarse Aggregate Gradation

Yi-zhou ZHUANG[1, a,] Er-bu TIAN[1, 2, b] Yue-zong LIAN[2, c]

[1]Fuzhou University, Fuzhou, Fujian Province, China, 350002

[2]Sanming University, Sanming, Fujian Province, China, 365004

[a]478372092@qq.com, [b]teb0310@163.com, [c]lianyuezong@163.com

Keywords: High-strength concrete; Coarse aggregate; Skeleton; Steel slag; Uniform design.

Abstract. People often mix superplasticizer and particulate to increase the density of high-concrete, but ignoring the effect of coarse aggregate gradation on concrete strength. Referring to several Gradation Theories, this paper selects the coarse aggregate gradation with skeleton, uses uniform design method to test the compressive strength of high-strength concrete, and analyses the test results. It can be known from the test results of 7d and 28d concrete specimen that the concrete strength decreases linearly with water-cement ratio and sand ratio; The 7d's concrete strength has higher variability due to low water-cement ratio with superplasticizer; The coarse aggregate skeleton is interfered by the increase of steel slag and sand rate, and the concrete strength decreases with limited cement paste. Furthermore, the steel slag with less than 30% addition has little effect on concrete strength and it can increase the cement's possibility of contacting to water, and reduce the amount of cement without lowering the concrete strength. The influential degree on the compressive strength of concrete is followed by ascending sequence of steel slag content, sand ratio and water-cement.

Intorduction

According to the composition principle of ordinary concrete strength, it shows that the strength of ordinary concrete is mainly determined by the interface strength between cement and aggregate, but it always ignores the fact that the coarse aggregate gradation composition affects the concrete strength in proportion design. People always think that concrete owns the very density just for its high intensity, and often add superplasticizer or something (such as steel slag, slag, etc) capable of increasing strength to improve concrete density; however, this concept overlooks the contribution of aggregate strength to concrete. No matter whether it is the ordinary or high strength concrete, the volume of aggregate in it accounts for about 70% of the total volume. There are few studies on how the aggregate strength and the concrete structure types affect on concrete strength, especially on high strength concrete strength, but there is rarely relevant report about it. In order to avoid aggregates from fracture damage and satisfy workability in concrete construction, the relevant specifications and regulations, domestically and internationally, of concrete and aggregate just provided some related provisions for the flaky aggregate. The existing papers about them on composition of coarse aggregate are very few. Even if the composition is within the relevant specification-recommended grading curve range, most of it is the continuous density grading. According to Wu Zhong-wei's "centroplasm hypothesis" -the particle interference theory, Liu Chongxi's theory of continuous density surrounded by stacks, the volume method and so on [1-3], some researchers suggest different aggregate gradations such as Ma-biao's proposal of interlocking-dense coarse aggregate gradation [4], and Wang Li-jiu's coarse aggregate gradation [5]. This paper uses the above two theories for references, chooses the materials of interlocking-dense structure coarse aggregate, uses the uniform design method for strength test, and analyses the relationship between the strength with water-cement ratio, sand ratio, aggregate-pulp ratio, in order to find out the effect of interlocking-dense structure coarse aggregate on concrete strength.

Material properties

Raw materials

All materials used in the experiments are produced in China.

Cement: the cement is grade 42.5R Portland cement named Jianfu, produced in Yongan of Fujian Province. Its properties can be found in Table 1.

Table 1 Cement properties

Water requirement for normal consistency(g)	80μm sieving residue (%)	Initial set time (min)	Final set time (min)	Density (g/cm^3)	Stability	Surface area(m^2/kg)
139	3.1	140	390	3.12	eligibility	402

Coarse aggregate: the coarse aggregate is granite stone ground in Sanming of Fujian Province, and its properties are listed in Table 2.

Table 2 Coarse aggregate properties

Test Index	Specifications(Ⅰgrade)			Measured Values			
Crushed stone value (%)	＜10			5.6			
Density(g/cm^3)	≮2.5			2.714			
Flakiness and spicula in coarse aggregate（%）	＜5			3.0			
Sieve Size（mm）	26.5	19	16	13.2	9.5	4.75	2.36
Apparent Density (g/cm^3)	2.709	2.696	2.702	2.698	2.701	2.710	2.731
Accumulated Density (g/cm^3)	1.521	1.537	1.517	1.522	1.544	1.566	1.604

Fine aggregate: the fine aggregate is dredged in the river named Shaxi, Sanming, Fujian Province. Its fineness modulus is 2.67 and belongs to medium sand, and all its indexes were measured up. Its properties are listed in Table 3.

Table 3 Fine aggregate properties

Sieve Size /mm	4.75	2.36	1.18	0.6	0.3	0.15	0.075	Accumulated Density (g/cm^3)	Apparent Density (g/cm^3)
Accumulated screening rate /%	85.40	64.35	30.71	16.05	5.23	1.54	1.65	1.572	2.786

Superplasticizer: the superplasticizer is produced by a new building materials center named Putian Xinhua in Fujian Province, and is an admixture of FDN. The optimum mixing content is 1.3%.

Steel slag: The steel slag is produced by a company named Xinsheng, Sanming, Fujian Province. The properties of the steel slag are shown in Table 4.

Table 4 Steel slag properties

CaO (%)	MgO (%)	P_2O_5 (%)	f-CaO (%)	Surface Area(m_2/kg)	Fluidity (mm)	SO_3 (%)	7d-activity Index	28d-activity Index
37.6	8.1	1.30	0.65	433	105	0.19	77	80

Test Method

According to Chinese standard “Standard for test and evaluation of concrete compression strength “(GB50107－2010) and “code for design of concrete structure” (GB 50010-2002）, this study used Uniform Design Method to design the test and adopted the compressive strength test on 150mm×150mm×150mm specimen. Each group of the compressive strength test has six specimens with ages of 7 to 28 days.

Coarse aggregate grading

According to Ma-biao's vibrating-filling test results, and by combing Wang li-jiu's coarse aggregate architecture gradation, the interlocking-dense coarse aggregate gradation was selected, and its gradation curve is shown in Fig.1. Its percentage of voids in aggregate is 36.4%. In order to maintain the skeleton structure after final setting of concrete, the sand percentage must be less than 36.4%.

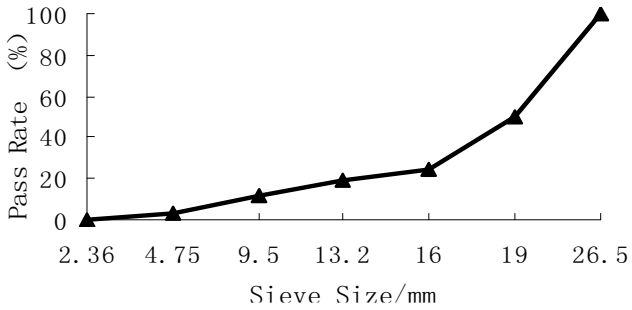

Fig.1 The curve of the pass rate of the coarse aggregate gradation

Experiment design

The factors which have significant impact on concrete workability and strength are often water-cement ratio x_1, sand percentage x_2 and steel slag addition x_3 ($m_{sl}/(m_{sl}+m_c)$). This paper studies the relationship between concrete strength and water-cement ratio, sand percentage, as well as steel slag addition. According to relevant research, strength has usually linear correlation with water-cement ratio, sand ratio, and steel slag addition. Therefore, a quadratic polynomial representing the relationship between strength and factors is shown in equation 1.

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1x_2 + a_5x_1x_3 + a_6x_2x_3 \quad (1)$$

Where m_{sl} is the weight of steel slag; m_c is the weight of cement; $a_0, a_1, \ldots a_6$ are constants. The strength test was carried out by using the Uniform Design Method that is an experimental design method spreading testing points evenly in the entire test program, and that has the advantage of finding out the correlation between index and factor with minimal number of tests. This research used U_6^* in the test design, which reduced the number of tests compared to the traditional method or orthogonal method. Every factor and its value range are shown in Table 5.

Test results

According to the Uniform Design table (shown in Table 5), three specimens in each age of each group were tested, and their average value of testing strength was taken as the intensity representative for that group. If the difference between the maximum value **or** minimum value and the intermediate one in the three measured values is relatively more than 15%, the intermediate value was selected as the intensity representative for that group. If the difference either between the maximum value and the intermediate one or the difference between the maximum value and the intermediate one is more than 15%, that group test is claimed to be invalid. Table 5 shows the test values.

Table 5 Uniform design table and testing values

Group	W/C	Sand ratio	Steel slag addition/%	7d strength	28d strength
1	0.27	0.32	10	77.7	83.8
2	0.28	0.34	25	64.2	74.3
3	0.29	0.36	5	68.7	80.0
4	0.30	0.31	20	67.8	78.0
5	0.31	0.33	0	68.3	82.6
6	0.32	0.35	15	68.0	78.8

Result Analysis

According to the test results of Table 5, we can get analysis results shown in Tables 6, 7.

Table 6 Analysis results of strength (1)

Constant	7d	28d	Regression parameters	7d	28d
a_0	135.7	114.9			
a_1	-114.9	-26.5	Multiple R	0.73	0.92
a_2	-85.1	-67.5	R Square	0.54	0.84
a_3	-0.3	-0.3	Adjusted R Square	-0.14	0.60
a_4,a_5,a_6	0	0	Standard Error	4.8	2.17

Table 7 Analysis results of Strength (2)

Group	Prediction y		Residual		Residual Standard	
	7d	28d	7d	28d	7d	28d
1	73.9	82.1	3.7	-2.10	1.2	-1.30
2	67.0	75.4	-2.8	1.09	-0.9	0.67
3	69.5	80.5	-0.8	1.01	-0.3	0.62
4	68.6	78.6	-0.8	1.01	-0.3	0.62
5	71.1	83.7	-2.8	1.09	-0.9	0.67
6	64.3	77.1	3.7	-2.10	1.2	-1.30

The Multiple R in Table 6 is the complex correlation coefficient, which is also called correlation coefficient, and is the measured size of the correlation between x_1, x_2, x_3 and y. R Square means the retest determination coefficient, and explains the degree of becoming worse of the dependent variable with the independent variable, for measuring the fitting effect of the dependent variable y. Adjusted R Square is the adjusted determination coefficient and used to measure the fitting degree of the joint independent variable model. Standard Error is used to measure the size of the fitting degree, and the smaller the value is, the better fitting degree is. From Table 6, the 7d strengths by Multiple R, R Square, Adjusted R Square, and Standard Error are respectively 0.73, 0.54, -0.14 and 4.8，which indicates that the fitting effect of equation is fair between 7d compressive strength y and variable x_1, x_2, x_3. However, the 28d strengths by Multiple R,R Square, Adjusted R Square and Standard Error are respectively 0.92, 0.84, 0.60 and 2.17, indicating the fitting equation of 28d compressive strength with variable x_1, x_2, x_3 is well. The reason that causes the above difference between the 7d and 28d strength in Multiple R, R Square, Adjusted R Square and Standard Error is that the 7d's strength has higher variability due to low water-cement ratio with superplasticizer.

Both in 7d and 28d strength, the regression coefficient a_0, a_1, a_2, a_3 are not zero, and the other regression coefficients are 0, which means that the relationship of strength y with water-cement ratio x_1, sand ratio x_2 and steel slag addition x_3 is linear. The value of a_1 is negative, which means that the strength decreases linearly with water-cement ratio. The 7d value is more magnificant than the 28d value, which indicates that water is very important for the early hydration of cement and that the early strength develops rapidly with the action of the superplasticizer when the water-cement ratio is small. The sand ratio a_2 is negative, indicating that the strength decreases with the increase of sand ratio, and that it can be explained as follows. The ratio of the interface strength accounts for greatly increases in high strength concrete compared to ordinary concrete, and the total interface increases with sand ratio increase, and the strength decreases with limited water and cement. Therefore, reducing the total interface as well as increasing the amount of coarse aggregate and the relative amount of cement paste can improve concrete strength. It becomes necessary to select the gradation of coarse aggregate skeleton structure and reduce sand ratio in order to improve the strength. The value of a_3 is -0.3, which indicates that the mount of the steel slag has little effect on concrete

strength with x_3 less than 30%. The correlative research shows that there is an effect on concrete strength just with steel slag addition x_3 of more than 30% [6], and it can increase the chance of cement's contacting to water, and decrease the amount of cement without decreasing the concrete strength. Therefore, some replacement of cement by steel slag will reduce the amount of cement and engineering cost. The inequality formulas $|a_1| > |a_2| > |a_3|$ explains the influence degree of water-cement ratio, sand ratio and integrating pulp effect on the compressive strength.

From Table 6, the regression equations of 7d, 28d compressive strength can be expressed as formula 2, 3:

$$y = 114.9 x_1 - 85.1 x_2 - 0.3 x_3 + 135.7 \quad (2)$$

$$y = 26.5 x_1 - 67.5 x_2 - 0.3 x_3 + 114.9 \quad (3)$$

In addition, Prediction y, Residual and Residual Standard in Table 7 can be computed by formula (2), (3).

Conclusions

This study leads to the following conclusions:

(1) Uniform Design's advantage is to find out the rule between index and factor with minimal number of tests.

(2) The concrete strength decreases linearly with water-cement ratio and sand ratio.

(3) The 7d's strength has higher variability because of low water-cement ratio with superplasticizer. In addition, the coarse aggregate skeleton is interfered by the increase of steel slag and sand rate, meanwhile the concrete strength decreases with the increase of lacking cement paste.

(4) The steel slag has little effect on concrete strength when the steel slag content is not more than 30%, but it can increase the chance of cement's contacting to water and decrease the amount of cement without decreasing the concrete strength.

(5) The influential degree on the compressive strength of concrete is water-cement ratio>sand ratio> steel slag addition.

Acknowledgement

This study is financially supported by Natural Science Foundation of China (Grant NO. 51278126) and Fujian Provincial Department of Education projects (Grant NO. JA12307). The authors would like to express gratitude to Professor Wang Feng-chao for his partial work.

References

[1] Zhongwei Wu. The Interface Problems of Cement-based Composite Material. Journal of Wuhan Building Material University, 1982(2).

[2] Shiyuan Huang, Jiafeng Jiang, etc. Modern Concrete Technology, Shaanxi Science and Technology Press, Xian, 1998.

[3] Congxi Liu, Ziyun Wen, Zaiqing Wang, Performance and Manufacturing Process of Concrete Aggregate, South China University of Technology Press, Guangzhou,1999, 25-35.

[4] Erbu Tian, Biao Ma, Xueming Lu, Yanqiang Shi, Vibration analysis on coarse aggregate gradation of interlocking-dense cement concrete, Concrete, 2008, 221(3), 77-83.

[5] Ancheng Wang, Coarse Frame Characteristic and Reaserch on Frame Concrete, Dalian University of Technology, Dalian, 2006, 15-17.

[6] Zhongwei Wu, Huizhen Lian. High performance Concrete. China Railway Publishing Press, Beijing 1999(1).