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Research Article

Experimental Study on Compressive Strength and Elastic Modulus of Ferrous Mill Tailing Concrete

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Abstract

In the aim at developing and utilizing ferrous mill tailing resources to save energy, protect environment and develop sustainable society, the experimental study on ferrous mill tailing (FMT) concrete are carried out. The strength grades of concrete used in tests are C30, C35, C40, C45, C50 and C55. Based on the compressive tests, the cubic strength and prism strength of FMT concrete along with their relationship were obtained. Meanwhile, with prism compressive test, the elastic modulus of FMT concrete and its relationship with compressive standard strength also were obtained. The test results show that the ratio of prism compressive strength to cubic compressive strength for FMT concrete is about 0.8-0.9 and the FMT concrete elastic modulus increase with its strength grades.

Keywords: environmental protection, experimental study, compressive strength, elastic modulus, ferrous mill tailing

1. Introduction

With development of concrete technology, the quantity of consumption for natural sand is growing quickly. The shortage of natural sand resources, the growing costs of exploiting natural sand is bringing about challenge for and restricting development of the premixing concrete industry as a whole. Using ferrous mill tailing as the alternative of natural sand in concrete is an effective way to resolve this issue. Powdery mill tailing from magnetite (also called ferrous mill tailing) is the remaining material of iron ore after processed, grinded and magnetic separation. As a discharged waste, it is largely accumulated in rivers and land, polluting the surrounding areas of the natural environment. Iron ore is a rich resource in Tangshan. Some large-scale state owned companies such as Capital Steel Group is located in Qian'an of Tangshan City. Every year, discharged ferrous mill tailing by steel companies is up to about 10 million tons, occupying 2,000 acres of farmland, seriously polluting the Luan River basin. The utilization of this ferrous mill tailing is beneficial to environment protection and social sustainable development.

Nowadays, the study and utilization of ferrous mill tailing mainly focuses on concrete used in expressway engineering [1-3]. Recently years, some study on concrete properties of ferrous mill tailing concrete which is used in building structures are carried out and research findings have been obtained [4-5]. Yet, these studies are almost conducted on concrete which is mixed with part natural sand and part ferrous mill tailing.

In this paper, the approach to the study focus on the compressive strength and elastic modulus of FMT concrete which is mixed with fine aggregate of 100% ferrous mill tailing aiming at using ferrous mill tailing more sufficiently.

2. Experimental materials

The comparison test approach is employed in the study. So the fine aggregates of each mixing ratio group include two cases of natural sand and ferrous mill tailing. Testing material description, technical index and origin are listed in Table 1.

Cement. The test-used cement is P.O42.5R Common Portland Cement, the production of Jidong Cement Company Limited. The properties of the cement are listed as Table 2.

Fly Ash. The test-used fly ash is Grade Ⅱ Fly Ash produced by Tangshan Power Plant. The chemical composition of it is listed as Table 3.

Slag Powder. The fine mineral powder is selected from Blast Furnace Slag produced by Tangshan Iron and Steel Company Limited. Its chemical composition is listed in Table 4.

Ferrous Mill Tailing. The selected ferrous mill tailing is discharged by Capital Steel Group in Qian'an. Through chemical analyses, its mineral composition and chemical composition are listed in Table 5 and Table 6 respectively.

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3. Compressive Strength program

The goal of this program is determination of prism compressive strength and cubic compressive strength of ferrous mill tailing concrete to clarify the ratio of them and compare it with that of common concrete. Since, the concrete strength grades consist of C30, C35, C40, C45, C50 and C55. As designing the mixing ratio of each grade ferrous mill tailing concrete, admixture of flyash, slag powder and addictive should be applied to modify concrete strength, dump and divergence. According to the JGJ55-2011(Specification for mix proportion design of ordinary concrete)[6] and GB50119-2003(Code for utility technological of concrete admixture) [7], the mixing proportion of each grade are listed as Table 7.

Table 1. Materials Used in Tests

Material	Cement	Natural Sand	Ferrous Mill Tailing	Gravel	Slag Powder	Fly Ash	Admixture
Technical Index	P.O42.5	MiddleII	MiddleII	5-25*mm*	S95	II	Composite
Origin	Jidong Co.	Luan River	Qian'an	Fengrun	Tanglong Co.	Douhe Power Co.	Tangshan

Table 2. Properties of P.O42.5R

Surface Area Ratio [m^2/kg]	Setting Time		Compressive Strength [MPa]		Breaking Strength [MPa]		Fineness [%]	Stability
	Initial [min]	Final [min]	3d	28d	3d	28d		
385	110	150	25.5	50.5	5.8	9.5	1.3	Qualified

Table 3. Chemical Composition of Grade Ⅱ Fly Ash

Composition	Loss on Ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	H_2O
Content[%]	6.81	64.50	19.50	3.40	9.41	6.82	0.03	0

Table 4. Chemical Composition of Slag Powder

Composition	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	K_2O	Na_2O	Alkaline Coefficient
Content[%]	35.95	8.71	1.96	11.52	37.42	0.51	0.76	0.91

Table 5. Mineral Composition of Ferrous Mill Tailing (%)

Composition	Quartz	Feldspar	Pyroxene	Magnetite	Others
Weight Ratio	40	20	20	10	10

Table 6. Chemical Composition of Ferrous Mill Tailing (%)

Composition	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	K_2O	Na_2O	CaO	MgO	SO_3
Weight Ratio	72	4.4	0.2	12.9	1.1	1.1	2.9	3.8	0.4

Table 7. Mixing Proportion (kN)

Grade	Ferrous Mill Tailing	Cement	Fly Ash	Slag Powder	Gravel	Water	Admixture
C30	884	220	75	105	997	169	7
C35	849	270	80	100	997	161	10
C40	817	320	80	90	999	159	12
C45	723	370	60	80	1049	176	14
C50	695	400	65	85	1049	169	16
C55	684	420	70	90	1038	166	17

For measuring the cubic compressive strength of FMT concrete, the specimens demission meets the specification of GB50081-2002 (Standard for test method of mechanical properties on ordinary concrete)[8] with 150 mm x 150 mm x 150 mm, as curing condition of temperature 20±2℃ and moisture of 95% for 28d. Meanwhile, the prism specimens demission is 70 mm x70 mm x210 mm with the same curing condition. Each specimen group consists of 3 same specimens.

According to the test method of GB50081-2002, tests carried out at hydraulic universal tester. The compressive strength is calculated as:

$$f = F / A \quad (1)$$

Where, f : the compressive strength (kN/mm^2)

F : failure loading(kN)

A : compressive area(mm^2)

The experimental results of cubic compressive strength and prism compressive strength are listed in Table 8 and Table 9 respectively.

Based on Data in the Table 8 and Table 9, the relationships between cubic compressive strength with concrete grade and prism compressive strength with concrete grade are curved in Figure 1. Then, the ratio of prism compressive strength to cubic compressive strength was figured out which is indicated in Figure 2.

Table 8. Cubic compressive strength

Specimen Number	Grade	*F* (kN)			Mean(kN)	*f* (MPa)
A1(1-3)	C30	1172	1228	1192	1176	53
B1(1-3)	C35	1300	1200	1237	1212	55
C1(1-3)	C40	1320	1320	1323	1330	59
D1(1-3)	C45	1400	1264	1333	1336	59
E1(1-3)	C50	1258	1432	1351	1364	60
F1(1-3)	C55	1700	1200	1477	1530	66

Table 9. Prism compressive strength

Specimen Number	Grade	*F* (kN)			Mean(kN)	*f* (MPa)
A2(1-3)	C30	210	218	218	215	44
B2(1-3)	C35	232	208	220	220	45
C2(1-3)	C40	252	234	240	242	49
D2(1-3)	C45	254	250	254	252	51
E2(1-3)	C50	235	284	260	260	53
F2(1-3)	C55	268	270	272	270	55

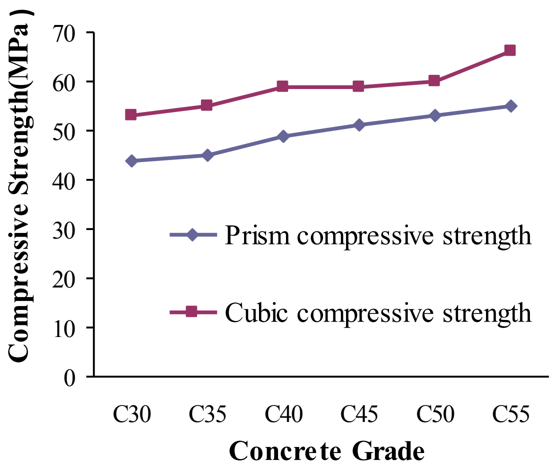


Fig.1 Relationship of strength and grade

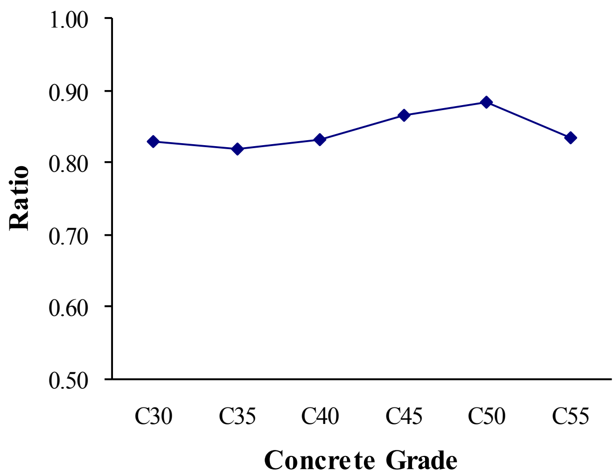


Fig. 2 Relationship of ratio and grade

As indicated in Figure 2, the ratio of prism compressive strength to cubic compressive strength of FMT concrete is between 0.8-0.9, that is, f_{ck}/f_{cu}=0.8-0.9. According to GB50010-2010 (Code for design of concrete structure)[9], the ratio of prism compressive strength to cubic compressive strength of ordinary concrete is between 0.7-0.92. Hence, the test results indicate that the ratio of prism compressive strength to cubic compressive strength of FMT concrete is in the cope of that of ordinary concrete.

4. Elastic Modulus Program

The elastic modulus of concrete is the key property for concrete structure design. For the use of FMT concrete in the structures, the FMT concrete elastic modulus must be determined. In this program, 21 specimens of 150mm×150mm×300mm are fabricated and tested, with 3 specimens in each strength grade of C30, C35, C40, C45, C50 and C55. The concrete mix proportions are the same as Table 7. The test technology Complies with the standard of GB50081-2002. The test setup is showed in Figure 3.

Fig. 3 Test panorama

Based on the test data, the concrete modulus E are calculated as:

$$E = f / \varepsilon \quad (2)$$

Where,
f is the concrete stress, which is calculated as equation (1).
ε is the concrete strain which is measured through strain gauges pasted on specimens.

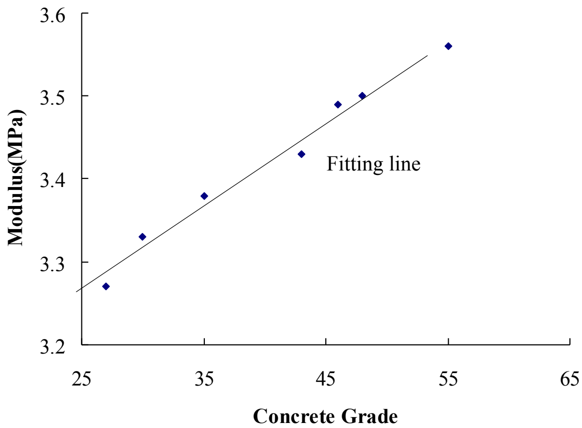


Fig. 4 The relationship of modulus with concrete grade

Table10. The elastic modulus

Specimen number	Prism strength (MPa)	Cubic strength (MPa)	Cubic standard strength (MPa)	Modulus (MPa)
WKS1-4	26	34	27	3.27
WKS1-5	29	38	30	3.33
WKS1-6	33	43	35	3.38
WKS2-4	41	54	43	3.43
WKS2-5	43	57	46	3.49
WKS2-6	44	58	48	3.50
WKS3-4	50	66	55	3.56

Table11. FMT concrete elastic modulus (10^4N/mm^2)

Strength grade	C25	C30	C35	C40	C45	C50	C55
E	3.25	3.30	3.35	3.40	3.45	3.50	3.55

The test results are listed in Table 10.

Based on the data listed in Table 10, the vary curve of modulus with concrete grade is plotted in Figure 4, in which the straight line is fitting straight-line.

As indicated in Figure 4, it can be include that the modulus of FMT concrete increases with its cubic standard strength from 3.27MPa with strength of 27MPa to 3.56MPa with strength of 55MPa. In figure 4, according to the curve vary, a straight fitting line was plotted. With this fitting line, the FMT concrete modulus with each strength grade can be listed in Table 11.

5. Stress-strain relationship of FMT concrete

For measuring the stress-strain relationship of FMT concrete, 30 specimens with dimension of 70mm×70mm×210mm are fabricated and tested, each group includes 3specimens and the concrete grades are C20, C25, C30, C35, C40, C45, C50 and C55. The curing condition is the same as the elastic modulus specimens.

The stress-strain relationship tests are carried out at LVDT loading instrument, which is indicated as Figure 5.

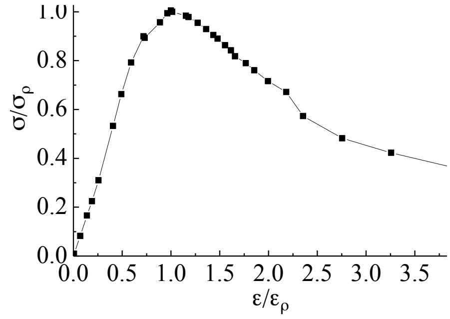
Fig. 5 LVDT installation

The test data are listed in Table 12.

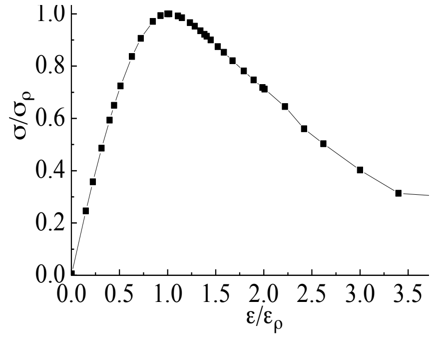
Table 12 Stress-strain test data

Number	Peak Stress	Peak Strain	Peak Stress	Peak Strain	Peak Stress	Peak Strain
A(4-6)	173	1518	137	1577	150	1568
B(4-6)	193	1306	184	1566	197	1417
C(4-6)	214	1416	190	1233	193	1300
D(4-6)	285	1753	239	1516	241	1543
E(4-6)	231	1301	262	1400	230	1322
F(4-6)	304	1722	298	1628	261	1510
G(4-6)	334	1796	270	1353	312	1482
H(4-6)	298	1706	317	1773	307	1896

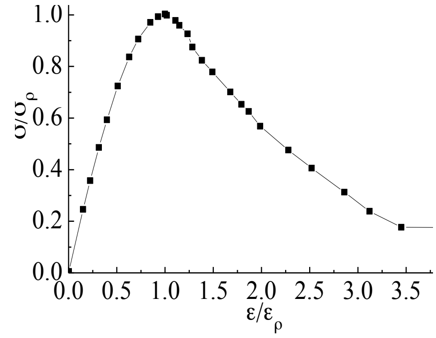
With the test data, some of the stress-strain relationship curves of FMT concrete with various strength grades are illustrated in Figure 6.



(a) A-4 Stress-strain curves



(b) I-4 Stress-strain curves



(c) J-4 Stress-strain curves

Fig. 6 Some specimen stress-strain relationship curves

Figure 7 illustrates the stress-stain relationship curves of the specimens of A, C, D and H group which indicates that the peak strains with various strength grades vary little while the peak stresses increase with increasing grades, and the descent stages become steep with increasing strength grades.

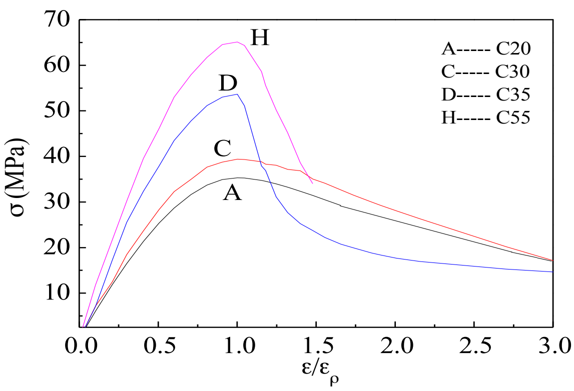


Fig. 7 Stress - Strain curve differential with various grades

4. Conclusions

Through experiments and analyses, the following conclusions are proposed:
1. The prism compressive strength of FMT concrete in this test is 0.8-0.9 times of its cubic strength.
2. The modulus of FMT concrete increases with its standard compressive strength.
3. A straight fitting line of relationship between modulus and standard compressive strength of FMT concrete was figured out according to the test results.
4. The stress-strain relationships of various strength grades of FMT concrete are obtained.

Acknowledgements
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