CHEMICAL ENGINEERING TRANSACTIONS
VOL. 66, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216
DOI: 10.3303/CET1866111

Microstructure Analysis and Study on Mechanical Property of Cement Compound Based on Constitutive Relation

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Cement compound is an important component of building materials. Its microstructure and physical and mechanical properties are affected by admixture. Taking cement compound as the object of study, this study explores the effect of cement compound on the microstructure of cement concrete by adding different contents of coal gangue fine aggregates, as well as reveals the action mechanism of active coal gangue on cement concrete. When the content of coal gangue fine aggregate is 20%, the microstructure is compact. The relationship between compressive strength and axial compressive strength of coal gangue cement concrete is established by testing the compressive property of coal gangue cement compound (CGCC). The stress-strain curve of spontaneous combustion and non-spontaneous combustion of CGCC is obtained, and the compression constitutive model of CGCC is proposed.

1. Introduction

Cement compound (Bahar, 2004), i.e. cement concrete material, is the most widely used man-made material in infrastructure projects in modern society, such as expressways, airports, dams, houses, and factories. The development and change of cement compound technology (Palomo, 1999) embodies the social scientific and technological progress. Adding various additives to cement compound (Toutanji, 2015) will greatly affect its microstructure (Diamond, 2004) and mechanical property, Although the strength of cement compound has been improving all the time, its durability faces challenges and a lot of wastes are produced. Therefore, how to improve the microstructure to enhance and improve the mechanical property and durability of cement compound is the focus that researchers pay attention to at present.

The improvement and strengthening of property of cement compound is a process of changing its microscopic bonding interface by adding different admixtures to change its macroscopic property (Wu, 2003). The rich monox and alumina contained in coal gangue (Querol, 2008) can be mixed with cement compound as gravel to form concrete (Li, 2006), which can not only reduce the discharge of coal gangue (Sun, 2009), but also turn it into wealth for reutilization. At present, there have been few researches on the effect of cement compound added with coal gangue (Zhou, 2009) on the microstructure and property of cement compound. Therefore, based on the constitutive relation of cement concrete (Seibi, 2001), this study adds coal gangue aggregates with different contents were added to cement compound, analyzes and explores the microstructure and macroscopic mechanical property.

2. Theoretical Basis

2.1 Cement compound

The concrete material formed by the mixture of cement compound and gravel is the most widely used man-made material in the infrastructure projects in modern society. Figure (1) shows the main components of cement concrete.

Please cite this article as: Wen M., 2018, Microstructure analysis and study on mechanical property of cement compound based on constitutive relation, Chemical Engineering Transactions, 66, 661-666 DOI:10.3303/CET1866111

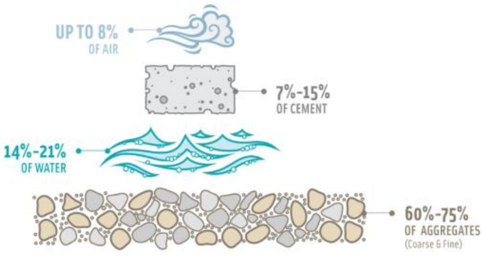


Figure 1: The Components of Concrete

2.2 Coal gangue

Coal gangue is the generic term of wastes discharged in the process of coal mine production. The monox and alumina contained in the compound can be changed into wealth after treatment, which can be added to cement compound or concrete as building materials. Table (1) is the main chemical components of spontaneous combustion and non-spontaneous combustion coal gangue.

Table 1: Main Chemical Components (by mass) of Metakaolin (wt %)

Components	SiO2	Al2O3	GaO	Fe2O3	Na2O	K2O	MgO
Natural Coal Gangue	58.05	20.66	1.46	6.6	0.21	2.32	0.97
Unnatural Coal Gangue	59.80	20.16	1.96	5.5	0.22	2.56	1.02

2.3 Constitutive relation

The constitutive relation (Chen, 2013) is a mathematical model that reflects the macroscopic property of material. The study of constitutive relation is the basis of cement compound structure, and the existing constitutive model is shown in Figure (2) below. At present, the more commonly used model is a trial-derived and form-concise nonlinear elastic model.

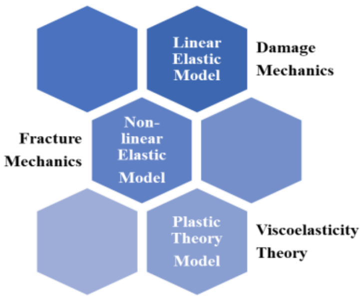


Figure 2: Constitutive Model Theory

3. Microstructure Analysis of the Action Mechanism of Coal Gangue Fine Aggregate on Cement Compound

3.1 Design of experimental scheme

This experiment is to study the influence of the amount of coal gangue fine aggregate on the microstructure and mechanical property of cement compound. The ratio of cement compound is shown in Table (2), where the water cement ratio is 0.4. The cement compound shall adopt the standard curing conditions: after form removal after casting for 24 hours, the standard curing shall be adopted with the relative humidity of 90% and temperature of 22 ° C, and then the conditions of 3 days, 7 days and 28 days shall be observed.

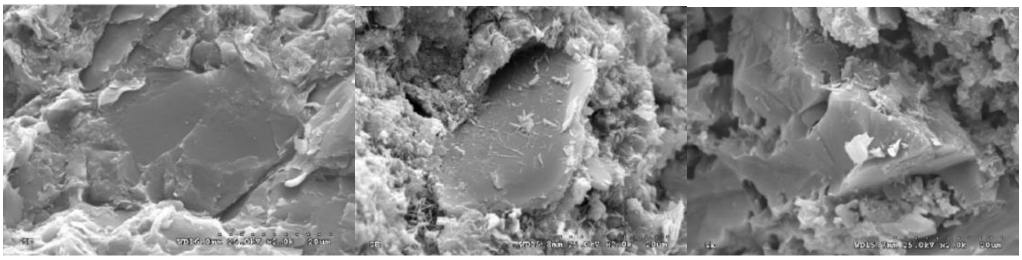
Table 2: Main Chemical Components (by mass) of Metakaolin (wt %)

Components	SiO2	Al2O3	GaO	Fe2O3	Na2O	K2O	MgO
Natural Coal Gangue	58.05	20.66	1.46	6.6	0.21	2.32	0.97
Unnatural Coal Gangue	59.80	20.16	1.96	5.5	0.22	2.56	1.02

3.2 Microstructure analysis of cement compound

The cement compound with curing period up to 28 days is selected and the interface between the coal gangue and the cement compound is selected in the crushed sample. In order to terminate the reaction, the compound is put into absolute ethyl alcohol for 24 hours and dried. The microstructure of the fracture is observed by electron scanning microscope to observe the reaction and distribution of coal gangue with different contents in cement compound.

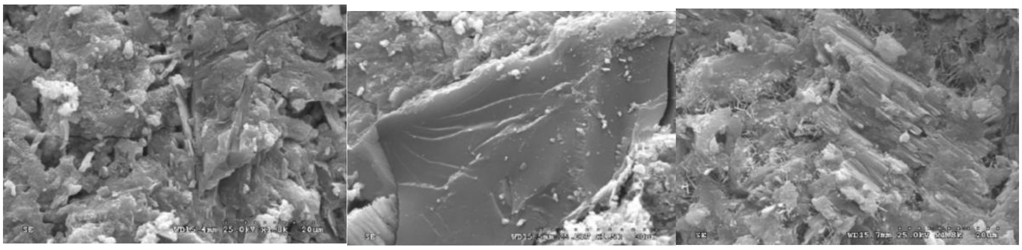
Figure (3) is the microstructure of the distribution of spontaneous combustion coal gangue with different contents in cement compound. It can be found from observation that the coal gangue has little influence on the microstructure of the cement compound and the active reaction of the spontaneous combustion coal gangue is low when the admixture is small. When the content is 20%, the coal gangue and the compound have active hydration reaction and produce a lot of hydration products to fill the microscopic pores, forming a relatively compact and stable structure. When the content is 30%, the hydration reaction produces more pore-like structure, and the structure is looser.



(a)10% (b) 20% (c) 30%

Figure 3: Microstructure of NCG-C with Different Contents at 28 Days

Figure (4) is the microstructure of distribution of non-spontaneous combustion coal gangue with different contents in cement compound. It can be found from observation that a small amount of hydration products are produced in the cement compound and the structure is less compact than that of spontaneous combustion coal gangue when the admixture is small. When the content is 20%, the hydration reaction is active and the compact net structure is formed. When the content is 30%, the effect of the initial defects of non-spontaneous combustion coal gangue on the microstructure is obvious, and a discontinuous pore structure is produced.



(a)10% (b)20% (c)30%

Figure 4: Microstructure of UCG-C with Different Contents at 28 Days

4. Analysis of Mechanical Property of Cement Compound Based on Constitutive Relation

4.1 Constitutive relation model

The stress-strain tendency in compression test of cement compound is the foundation to react the constitutive relation model of nonlinear change process of material. The constitutive model chosen in this study is a piecewise stress-strain nonlinear equation, and the formulas are as follows:

$$y = ax + (3-2a)x^2 + (a-2)x^3 \quad 0 \leq x \leq 1 \tag{1}$$

$$y = \frac{x}{a(x-1)^2+x} \quad x>1 \tag{2}$$

$$x = \frac{\varepsilon}{\varepsilon_c} \quad , \qquad y = \frac{\sigma}{f_c} \tag{3}$$

Where, f_c is axial compressive strength of cement compound, ε_c is the corresponding peak strain of f_c.

4.2 Compressive strength test

Compressive strength is one of the basic indexes to measure cement concrete which must meet certain compressive strength before it can be used for structure cutting. The formulas for compressive strength and axial compressive strength are as follows:

$$f_{cu} = \frac{F}{A} \tag{4}$$

$$f_c = \frac{F}{A} \tag{5}$$

Where, F is the limit load; A is the bearing area of the sample; f_{cu} is the compressive strength; f_c is the axial compressive strength of cement compound.
From the compression test and regression analysis of the obtained compression strength, as shown in Figure (5), the relationship between the two can be obtained:

$$f_c = 0.712 f_{cu} \tag{6}$$

$$f_c = 0.795 f_{cu} \tag{7}$$

Formula (6) is the relationship between the axial strength and the compressive strength of the spontaneous combustion coal gangue cement compound, and Formula (7) shows the relationship between the spontaneous combustion cement compound and non-spontaneous combustion cement compound

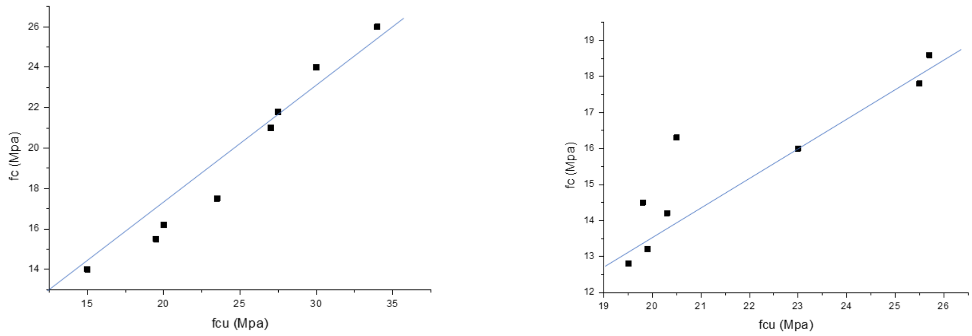


Figure 5: Regression Analysis of UCG and NCG'f_c and f_{cu}

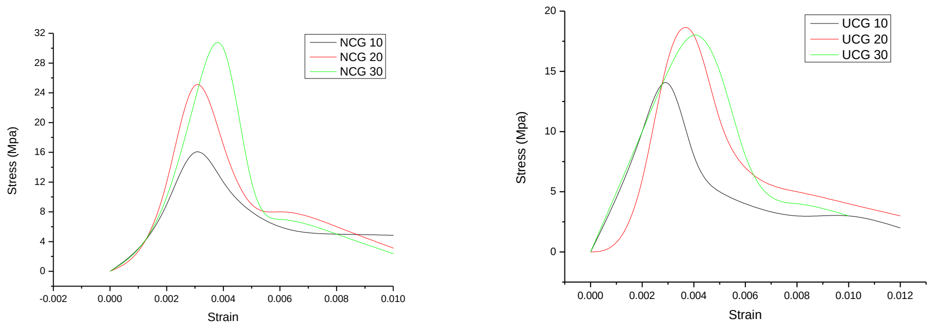
4.3 Stress-strain curve test of cement compound

The stress-strain curve of cement compound is one of the basic mechanical properties of cement material, reflecting the change of cement material under external load and the corresponding failure mechanism.
In this experiment, the rock mechanics test system is used to test the sample, and the axial stress-strain compression curve is drawn. Test sample is spontaneous combustion and non-spontaneous combustion coal gangue aggregate cement compound of different strength grades prepared in accordance with Table (3). The sample is cylindrical with dimension of 80mmX100mm. The test shall be conducted after 28 days of standard curing.
Figure (6) are stress-strain curves of spontaneous combustion and non-spontaneous combustion coal gangue aggregate cement compound of different proportions. When the external load is small, the stress increases linearly with the strain degree. When the proportional limit is reached, plastic deformation will occur in some

weak internal parts of the sample and the relationship between stress and strain is nonlinear until the critical point of Poisson's ratio 0.5 is reached. When the critical point is reached, the sample begins to swell gradually and the internal structure is discontinuous, forming a single peak on the curve. As the deformation continues, the crack continues to increase and the stress decreases sharply with strain. The stress-strain curve gradually tends to be flat after the inflection point is passed.

Table 3: The Mixture Design of Coal Gangue Concrete with Each Strength Garde

Grade	Cement (Kg/m^3)	Water-Cement Ratio	Coal Gangue Concrete (Kg/m^3)
NCG 10	280	0.73	1110
NCG 20	320	0.60	1050
NCG 30	380	0.45	1020
UCG 10	240	0.78	1160
UCG 20	300	0.65	1080
UCG 30	410	0.48	1040



(a) (b)

Figure 6: Stress-Strain Curve of NCG with Different Contents

Table (4) is the test result of stress-strain curve. Combined with Figure (6) and Figure (7), it is found that the peak stress of spontaneous combustion coal gangue aggregate cement concrete increases with the increase of content, and the peak stress of non-spontaneous combustion coal gangue aggregate changes in the strength of UCG30. The stress peak value of spontaneous combustion coal gangue is obviously higher than that of non-spontaneous combustion coal gangue, but there is no obvious difference in the corresponding strain.

Table 4: Main Testing Results of Coal Gangue Concrete Stress-Strain Relations Curves

Grade	f_c	ε_c	Destructive Form
NCG 10	15.5	0.0028	Shear
NCG 20	24.6	0.0035	Cleavage
NCG 30	29.4	0.0037	Cleavage
UCG 10	12.6	0.0028	Shear
UCG 20	19.2	0.0032	Cleavage
UCG 30	18.1	0.0033	Cleavage

5. Conclusions

The cement compound is taken as the object of study. This study explores the effect of cement compound on the microstructure and physical and mechanical properties of cement concrete by adding different contents of coal gangue fine aggregate. The research results are as follows:

(1) The action mechanism of active coal gangue on cement concrete is revealed by studying the microstructure of coal gangue fine aggregate on cement concrete. The interface of spontaneous combustion and non-spontaneous combustion coal gangue cement has compact structure and good macroscopic mechanical property when the content of coal gangue aggregate is 20%.

(2) The relationship between compressive strength and axial compressive strength of coal gangue cement concrete is established, the stress-strain curve of spontaneous combustion and non-spontaneous combustion CGCC is obtained by experiment, and the compression constitutive model of CGCC is proposed.

Acknowledgments

National Natural Science Foundation of China (Grant No:11702126); Youth Foundation of Nanchang Institute of Technology (Grant No. 2010KJ022)

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