Journal of Earth Science, *Vol.* 25, *No.* 2, *p.* 309–314, *April* 2014 *ISSN* 1674-487X
Printed in China
DOI: 10.1007/s12583-014-0414-x

Research on the Relationship between Grain Composition and Repose Angle of Coal Gangue in Dongkuang Mine, Heshan City, Guangxi, China

Zhaohui Tang*[1], Xinxin Dong[1], Yue Yang[2], Li Ma[1]
1. *Faculty of Engineering*, *China University of Geosciences*, *Wuhan* 430074, *China*
2. *Linyi Department of Land and Resources*, *Linyi* 276000, *China*

ABSTRACT: Heshan, a city in Southwest China, has been built over an old coal mining area. Due to low level of reclamation, coal gangue had been stacked in large heaps and caused geological environmental problems. To facilitate designing management project of coal gangue, we made an investigation of the largest coal gangue heap in Dongkuang Mine of Heshan. Firstly, the grain composition of coal gangue was estimated through the sieving method, then the representative grading curve was drawn through the statistics method of coarse grain content, and lastly the relationship between the repose angle and grain grading was studied by piling up coal gangue with different mix proportion. The result indicates that there is a wider range of grain size in the upper part of coal gangue heap, and the representative grain grading is well graded and easy to be compacted as filling materials. Besides, the wavy relationship curve of repose angle and coarse grain content shows that the content of 70% is the inflection point of ascent stage and 85% the inflection point of descent stage of the repose angle. What's more, the repose angle corresponding to the representative grading of coal gangue is approximately 38.4° and this has guiding significance for management project of coal gangue.
KEY WORDS: coal gangue, grain composition, representative grain grading, repose angle.

1 INTRODUCTION

In China, due to the lack of comprehensive utilization of coal gangue, the majority of them had been stacked in open air and become one of the largest solid wastes (Bi et al., 2005). Coal gangue has done extensive damage to environment, such as land destruction, water and soil pollution, etc. (Wang et al., 2006). Furthermore, unstable slope of coal gangues may threaten life and do harm to human health.

Heshan, a city located in Guangxi Zhuang Autonomous Region, Southwest China, owns the largest coal mine in Guangxi with over hundred years of coal mining history (see Fig. 1). Due to low rate of resource reclamation, large amounts of coal gangue have been stacked on surface and became typical solid wastes. According to researches, due to the lack of long-time consolidation caused by multiple times of screening residual coal, the stability of coal gangue heaps under natural conditions is controlled by the surface friction of grains. Because the cohesion strength is almost zero, the natural angle of repose could be the main strength parameter of coal gangue heaps. However, it is impossible to obtain mechanical parameters through indoor tests due to the fact that the compositions of coal gangue are complex and uneven. In the past, the in-situ shear test or analogies of experience were generally applied to determine the strength parameter (Tang et al., 2012; Liu et al., 2006; Duncan et al., 1980).

In recent years, the Chinese government has provided large amount of fund to cities faced with resources exhaustion to help them to solve mining-related environmental problems and to develop economy. Coal-mining cities like Heshan have taken various measures to improve their environment, of which coal gangue management project is of great importance. Our research selects Dongkuang coal gangue heap, the largest one in Heshan, as its object. Through in-situ grain sieving method, the grain size of coal gangue was determined and the grading composition was calculated and on this basis we can evaluate the suitability of coal gangue for backfilling collapse pits and goaf and filling the roadbed. Besides, through in-situ mix proportion test, the repose angle of coal gangue was measured and a systematic study was made on the change rule of natural repose angle of coal gangue in different ranges of grain size to provide guidance for the design of Dongkuang large coal gangue heap management project.

2 ANALYSIS OF GRADING COMPOSITION OF COAL GANGUE IN DONGKUANG

2.1 The Design of Grain Sieving Experiment

The grain sieving experiment was conducted at the northwest of the large coal gangue heap in Dongkuang, where the side slope of coal gangue extends 300 m, the slope height is

*Corresponding author: zhtang@cug.edu.cn

Manuscript received September 21, 2012.
Manuscript accepted January 27, 2013.

Tang, Z. H., Dong, X. X., Yang, Y., et al., 2014. Research on the Relationship between Grain Composition and Repose Angle of Coal Gangue in Dongkuang Mine, Heshan City, Guangxi, China. *Journal of Earth Science*, 25(2): 309–314, doi:10.1007/s12583-014-0414-x

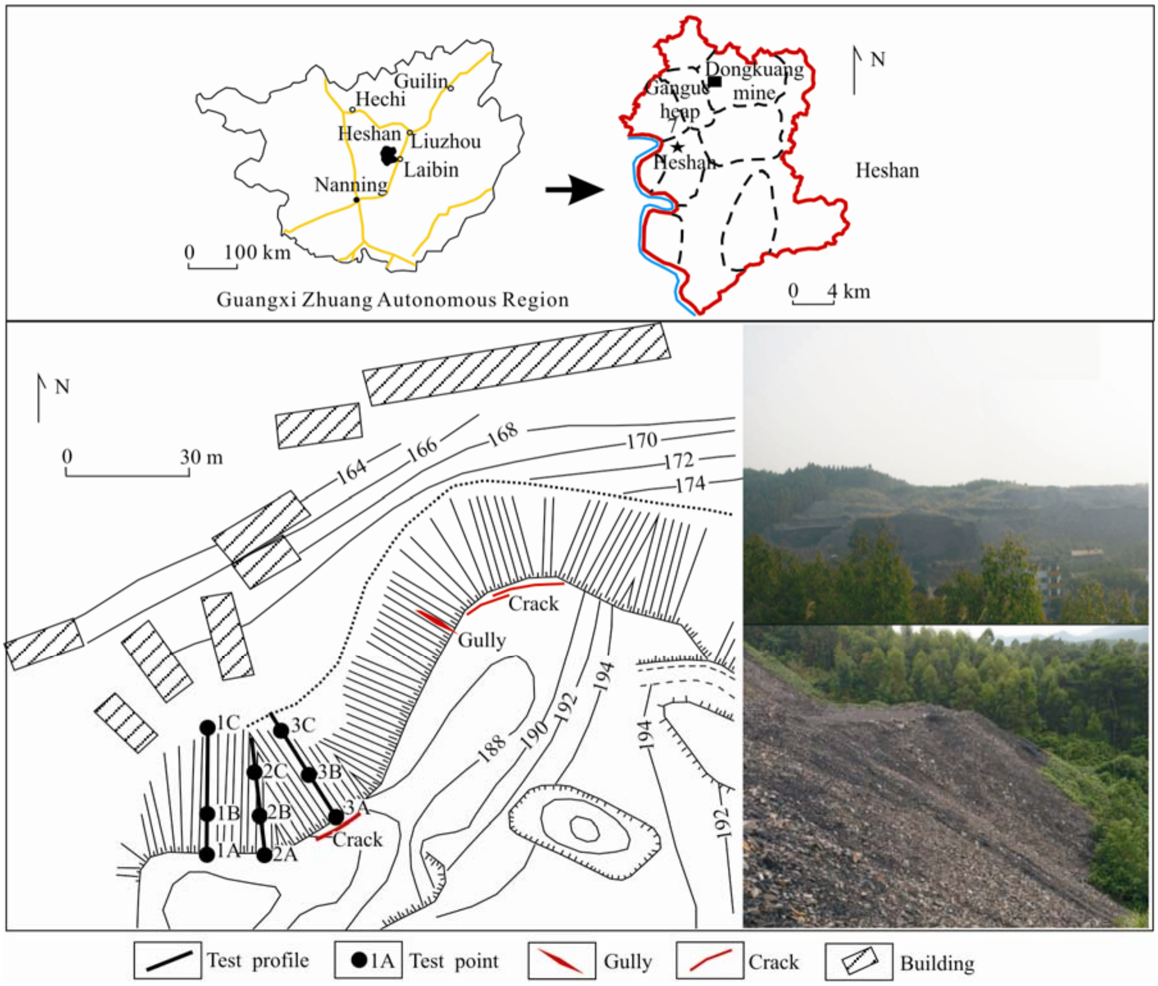

Figure 1. The large gangue heap and test sites in Dongkuang.

20 m and the slope angle is about 40°. Due to the lack of protective measures, several fractures have been developed at the top of the northwestern slope with the major one about 20 m long and 2–3 cm wide. The top terrace of the slope is a catchment area with a gully formed by rainwater, and there are bulges in the middle of the slope. With the dormitories of mineworkers and producing mines at the foot of the side slope, the lives of miners and the safety production are exposed to the risks of land slide and debris flow in extreme weather.

In the experiment, three profiles, namely profiles 1, 2 and 3, were selected on the unstable slope, each with three test sites, i.e., sites A, B and C, as presented in Fig. 1. Based on the actually measured grain sizes of coal gangue, we used special square mesh sieves for the sieving experiment, and the sieve sizes are 1.5, 3, 5, 12.5, 25, 35, 50, 65, 80, 100 and 150 mm, respectively. Since the grain sizes on the upper and middle part of the slope do not vary much, the same measuring scale was adopted, and the sieve sizes are 1.5, 3, 5, 12.5, 25, 35, 50, 80 and 100 mm, respectively. The grain sizes at the slope foot vary greatly, and therefore the sieve meshes of the sizes 35, 65 and 150 mm were added. Thirty kilogram of coal gangue was sampled at each test site and those of extremely irregular shape or giant grains were eliminated through the scalping method. Samples were sun dried, screened and weighed. The sample amount and test procedure comply with requirements of the Test Method of Soils and the Method for Size Analysis of Coal (Tangshan Research Institute of CCRI, 2009).

2.2 Grading Features of Grains

The grain size distribution of coal gangue at each test site is shown in Table 1. The mass distribution in each range of grain size indicates that there is more and wider range of fine grains at upper and middle test sites and those sized between 5–50 mm comprise over 60% of the total; and there are fewer fine grains at the bottom test site and the grain sizes vary greatly, ranging between 12.5–100 mm.

Grain grading curves were drawn through EXCEL (see Fig. 2) and grading parameters were obtained by calculating the mean grain size d_{50}, the uniformity coefficient C_u and the curvature coefficient C_c (see Table 2).

Figure 2 shows that grading curves of the upper and middle test sites are smooth with wide range of grain size and homogeneous distribution of coarse and fine grains. The grading curve of the bottom test site has even step with deficiency in grain size and the content of fine grains is obviously lower than that of the other two test sites. According to Table 2, the grain size of the middle test site is a little larger than that of the upper test site, and there is a sharp increase of grain size at the bottom test site which means that there are fewer fine grains at the bottom slope. However, grain sizes from upper to bottom do

Table 1 Grain mass percentage of the test sites in each grain size range

Sample No.	Grain mass percentage (%) in each grain size range (mm)							
	[80, 100]	[50, 80]	[25, 50]	[12.5, 25]	[5, 12.5]	[3, 5]	[1.5, 3]	1.5≤X
1-A	0.00	7.06	15.46	20.94	24.13	5.93	9.94	16.55
2-A	2.82	11.38	21.52	20.25	21.86	4.68	7.91	9.59
3-A	3.44	11.53	18.61	16.02	17.34	5.57	11.76	15.71
1-B	0.00	10.33	17.16	21.66	23.72	5.08	10.33	11.71
2-B	0.00	8.94	21.55	24.36	21.27	4.62	7.74	11.51
3-B	7.06	9.68	20.50	15.51	17.87	5.10	11.18	13.11

Sample No.	Grain mass percentage (%) in each grain size range (mm)										
	X≥100	[80, 100]	[65, 80]	[50, 65]	[35, 50]	[25, 35]	[12.5, 25]	[5, 12.5]	[3, 5]	[1.5, 3]	1.5≤X
1-C	0.00	0.00	14.30	15.88	18.52	27.30	16.25	3.89	0.52	1.21	2.13
2-C	2.34	17.49	16.93	11.89	19.06	9.51	11.72	5.07	0.91	1.99	3.08
3-C	5.89	9.69	12.58	14.84	29.41	3.72	9.16	6.24	1.52	2.77	4.19

Table 2 Grading parameters of the test sites

Sample No.	d_{10} (mm)	d_{30} (mm)	d_{60} (mm)	C_u	C_c	d_{50} (mm)
1-A	0.88	4.47	14.72	16.73	1.54	9.96
2-A	1.59	7.24	21.89	13.77	1.51	15.47
3-A	0.94	3.85	19.37	20.61	0.81	12.65
1-B	1.25	5.71	17.72	14.18	1.47	12.06
2-B	1.25	6.75	19.45	15.56	1.87	14.45
3-B	1.15	5.33	22.57	19.63	1.09	14.56
1-C	15.41	28.18	40.88	2.65	1.26	37.67
2-C	11.90	33.30	61.40	5.16	1.52	53.31
3-C	7.00	36.85	52.59	7.51	3.69	50.28

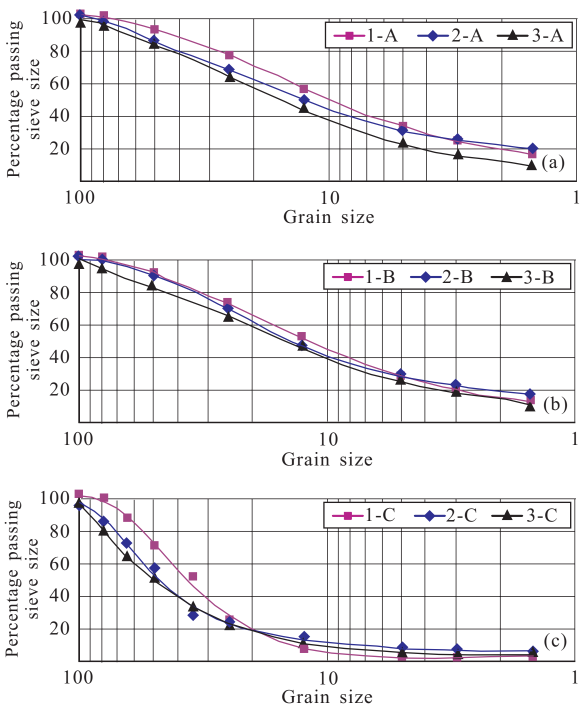

Figure 2. Grading curves of the test sites. (a) The upper test sites; (b) the central test sites; (c) the bottom test sites.

not increase in linearity. Previous studies indicated that the average grain size of bulky grains of soil dumping site is in exponential relationship to the relative height of the sampling sites (Wang et al., 2012). This paper has demonstrated the exponential relationship of grain distribution though it can hardly obtain the quantitative relationship of the mean grain size because of the rather small number of test sites in present research.

2.3 Representative Grading of Coal Gangue in Dongkuang

In view of different grain gradations, engineering characteristics of coal gangue in the same place may be different. However, only typical parameters can be selected for subsequent stability analysis. The following is how the representative grading of coal gangue was acquired based on the above-mentioned experiment.

Common methods for determining representative grading are the grading curve envelope diagram method, the arithmetic mean method of grain grading, the classification statistics method of coarse grain content (d>5 mm), and the percentage statistics method (Guo, 1999). This paper adopted the statistics method of coarse grain content to determine the representative grading. Nine screening samples were regrouped, and the grading of first four groups with large percentages was averaged to get the representative grading of coal gangue. The grain composition of the representative grading is listed in Table 3.

As is shown in Table 4 and Fig. 3, the representative grading curve of coal gangue in Dongkuang Mine is smooth with a wide-range grain size, its gradation parameters C_u>5 and 3>C_c>1. Therefore, the coal gangue is well graded, and is good to be used as filling materials (Hu et al., 2012; de Mello, 1977).

Table 3 Representative grading of coal gangue in Dongkuang

Grain size range	Grain mass percentage in each grain size range (mm)								
	[100, 150]	[80, 100]	[50, 80]	[25, 50]	[12.5, 25]	[5, 12.5]	[3, 5]	[1.5, 3]	<1.5
Representative grading	0.82	4.05	17.55	26.82	17.21	14.53	3.45	6.6	8.97

Table 4 Gradation parameters of the representative grading curve of coal gangue in Dongkuang

Gradation parameters	d_{10} (mm)	d_{30} (mm)	d_{60} (mm)	C_u	C_c	d_{50} (mm)	Coarse grain content
Representative grading	1.28	10.68	32.72	25.56	2.72	23.85	81.0%

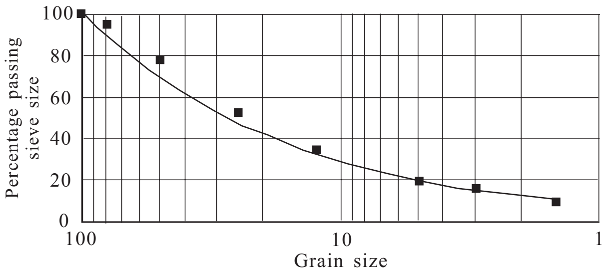

Figure 3. Representative grading curve of coal gangue in Dongkuang.

3 EXPERIMENT ON THE RELATIONSHIP BETWEEN REPOSE ANGLE AND GRADATION OF COAL GANGUE

3.1 Experimental Objective and Basis

The in-situ direct shear test once conducted in the large gangue heap of Dongkuang had failed to measure mechanical parameters of coal gangue because the loose grains of those test pits that had been dug up made it impossible to make sample preparation. In coarse grain theory and engineering practice at home and abroad, coal gangue is usually regarded as bulky material. Besides, grains of the shallow layer of the side slope of coal gangue leap are loose. So, a better option is to use the natural angle of repose as the internal friction angle to make related calculations.

In order to study the relationship between repose angle and grain grading to facilitate estimating the mechanical parameters of coal gangue under the condition that the grain size distribution is clear, a group of tests have been designed to analyze the relevance of repose angle to grain grading, and the relationship between physical and mechanical parameters of coal gangue, thus providing basis for qualitative and quantitative assessment of side slope stability of coal gangue.

3.2 Experimental Design of Repose Angle by Mix Proportion

This experiment was made in the northwestern side slope of large coal gangue heap in Dongkuang. Based on the preliminary survey and the data obtained in grain sieving experiment, the actual grain sizes were divided into five grades in descending order (see Table 5).

By referring to the research method of coarse grained soil, the experiment focuses on the change rule of mechanical properties along with the change of coarse grain content. According to the data obtained in grain sieving experiment, the mean grain sizes d_{50} of coal gangue grains in Dongkuang are mostly

Table 5 Grain size grading of coal gangue

No.	Grain size range (mm)	Grain size grades	Relative size
LJ1	80–50	Grade 1	Large grains
LJ2	50–25	Grade 2	Relatively large grains
LJ3	25–12.5	Grade 3	Medium-size grains
LJ4	12.5–5	Grade 4	Relatively small grains
LJ5	<5	Grade 5	Very small grains

distributed between 12.5 and 25 mm. To investigate the influence rule of coarse grain content on the repose angle, the grain content between 12.5 and 25 mm was maintained unchanged to keep regular changes between the smallest and smaller, and the largest and larger. On the basis of comprehensive consideration and calculations, a mix proportion was finally determined with better control of coarse grain content and fractal dimension (see Table 6 for the mix proportion and relevant gradation parameters). The coarse grain content controlled by the experimental design is within 65%–95%, exactly the same as the actual situation where coarse grains (≥5 mm) take up 65%–95% of the total in this area based on the data in grain sieving experiment.

Natural samples of coal gangue were screened and separated by grain sizes and mixed well according to proportions designed for each group of test (see Table 6). In each group of test, the mix sample was 100 kg and water content was basically the same. Mix samples were piled up in different groups using self-made support and funnel. Six sets of slope angles were measured by goniometry around the sample coal gangue heap. Two sets of data with much larger deviations were eliminated, and the average value of the remained four sets were taken as the repose angle of the coal gangue heap, as presented in Table 6. The sample amount and test procedure comply with requirements of the Test Method of Soils and the Method for Size Analysis of Coal (Tangshan Research Institute of CCRI, 2009).

4 DISCUSSION

The repose angle of coal gangue changes along with the content of coarse grains and fine grains. Coarse grains influence the repose angle through the interface friction and occlusion of grains, while fine grains are internal friction to do it. The friction angle of coarse grains is mainly from the binding force of grain angularities, and that of fine grains is mainly

Table 6 Mix proportions and related parameters

No.	[0, 5]	[5, 12.5]	[12.5, 25]	[25, 50]	[50, 80]	Coarse grain content	Repose angle
G1	5	10	20	30	35	95%	39.2
G2	10	15	20	25	30	90%	38.5
G3	15	20	20	20	25	85%	38.1
G4	20	20	20	20	20	80%	38.6
G5	25	25	20	15	15	75%	39.1
G6	30	30	20	10	10	70%	39.4
G7	35	35	20	5	5	65%	38.9

from the friction force and cohesive force (very small one) on grain surface. They work in the following way.

1. When coarse grain content is very high, grains have good friction that can interlock each other and form a skeleton of good stability. There are only a small number of fine grains dispersing in the pores with almost no influence on the repose angle. In this situation, if coarse grain content decreases, the repose angle will become smaller.

2. When coarse grain content decreases to a certain value, fine grains fill most of the pores, compactness increases under self-weight and the binding force of coarse grains remains almost unchanged. The increase of fine grain content enhances the sliding friction force. In this situation, if coarse grain content decreases, the repose angle will become bigger.

3. If coarse grain content continues to decrease, there will be no resistance force from coarse grains, and the friction angle of bulk material is mainly from the sliding friction force. In this situation, the more and the thinner fine grains are and the better their fluidity is, the smaller the repose angle is.

Some researches indicate that two typical features of the change of mechanical properties of coarse grained soil are coarse grain content being 30% and 70%, respectively (Guo, 1999). The relationship curve of repose angle and coarse grain content shows that the content of 70% is the inflection point of ascent stage and 85% the inflection point of descent stage of the repose angle (see Fig. 4). The coarse gravel gives play to the repose angle through the interface friction and occlusion of grains, but the small gravel is internal friction to do it. At the peak point of 70%, the small gravel could fill the interspace of coarse gravel well, and both of them support the repose angle together. With the increasing of coarse gravel, the small gravel can't fill the interspace of coarse gravel and reduce the interface friction of coarse gravel, and result in the trough point of the curve at 85%. When the content of coarse gravel was more than 85%, the repose angle would enhance with increasing interface friction of coarse gravels.

In Dongkuang, the mean content of coarse grains of the representative grading of coal gangue is 81.0% which is at the descent stage of the change curve of the repose angle. By fitting the curve, we estimate that the repose angle corresponding to the representative grading of coal gangue in this area is approximately 38.4° and this has guiding significance for side slope stability analysis and management project of coal gangue.

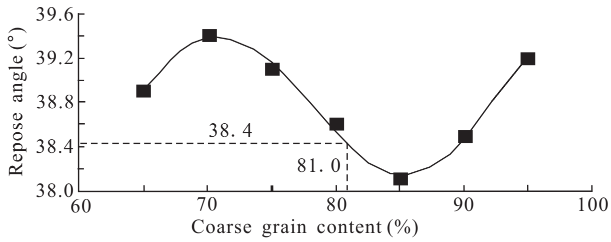

Figure 4. Relationship curve of repose angle and coarse grain content.

5 CONCLUSIONS

1. In the upper and middle part of coal gangue heap, there are more fine grains. Grains are wide-ranged and those with a size ranging between 5–50 mm take up over 60% of the total. At the bottom of the heap, there are fewer fine grains with large difference in grain gradation, distributed within the range of 12.5–100 mm.

2. The representative grading curve of coal gangue in Dongkuang is flat and smooth with a wide-range grain size. The uniformity coefficient *C*u of coal gangue is 25.56 and the coefficient of curvature *C*c is 2.72, which indicates that the coal gangue is well graded and easy to be compacted and therefore is good to be used as filling materials.

3. The repose angle of coal gangue is heavily influenced by the change of coarse grain content. In the wave-change curve of the repose angle, the content of coarse grains being 70% is the inflection point of ascent stage and 85% the inflection point of descent stage.

4. According to the change rule of the repose angle of coal gangue in Dongkuang, the one corresponding to the representative grading of coal gangue in this area is estimated to be approximately 38.4° and this has guiding significance for the design of management project of coal gangue.

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