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ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 1608−1617
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Dynamic mechanical properties and instability behavior of layered backfill under intermediate strain rates

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Received 11 April 2016; accepted 19 October 2016

Abstract: To obtain dynamic mechanical properties and failure rule of layered backfill under strain rates from 10 to 80 s^{-1}, impact loading test on layered backfill specimens (LBS) was conducted by using split Hopkinson pressure bar system. The results indicate that positive correlation can be found between dynamic compressive strength and strain rate, as well as between strength increase factor and strain rate. Dynamic compressive strength of LBS gets higher as the arithmetic average cement−sand ratio increases. Compared with static compressive strength, dynamic compressive strength of LBS is enhanced by 11% to 163%. In addition, the energy dissipating rate of LBS lies between that of corresponding single specimens, and it decreases as the average cement content increases. Deformation of LBS shows obvious discontinuity, deformation degree of lower strength part of LBS is generally higher than that of higher strength part. A revised brittle fracture criterion based on the Stenerding−Lehnigk criterion is applied to analyzing the fracture status of LBS, and the average relevant errors of the 3 groups between the test results and calculation results are 4.80%, 3.89% and 4.66%, respectively.

Key words: layered backfill specimen (LBS); split Hopkinson pressure bar (SHPB); dynamic mechanical properties; damage characteristic; failure criterion

1 Introduction

Due to the relatively low-level dilution ratio and flexibility, cut and fill stoping method is widely adopted in underground mines. To reinforce the working-face, reinforced backfill layer with higher strength is paved above the general backfill, thus backfill body presents a layered structure [1]. In Sijiaying Iron Mine (SIM), for example, under the condition of the same mass concentration of 72% and curing time of 28 d, the adopted cement−sand mass ratio of general backfill layer is 1:12 while that is 1:4 for the reinforced backfill layer, the maximum compressive strength of latter concreted backfill is 2.2 MPa, which is almost two and a half times that of the former. When excavation equipment works on the surface of concreted backfill body, or blasting operation of adjacent stope is under execution, dynamic load will be exerted on the layered backfill body. Due to different characteristics of backfill layers such as mass fraction, cement−sand mass ratio and porosity, the failure sensitivities of backfill layers to certain strain rate are distinctly diverse, dynamic load working on these backfill layers may lead to different levels of failure. It is unreliable to estimate the stability of layered backfill body on stopping site by using static mechanical properties obtained from common compression test on single structure specimens. Thus, dynamic failure strength should be regarded as an important reference to estimate the stability of layered backfill body under dynamic disturbance and complex deep mine environment [2]. However, no norm about dynamic mechanical properties of layered backfill has been taken into account in any mines. And there are few correlational studies on such issue. So far, several studies on the dynamic mechanism of layered concrete material have been implemented. DONG et al [3] analyzed the influence of dynamic stress on multi-layered media and pointed out that inferior constituent part of multi-layered media is the key factor which leads to deformation. LIU et al [4] studied the damage constitutive relation of stratified composite concrete and derived the damage evolution equation under different conditions. And several stability criterions of backfill body by associating

Foundation item: Project (2012BAC09B02) supported by the 12th Five-Year Key Programs for Science and Technology Development of China; Project (2016zzts444) supported by the Financial Support from the Fundament Research Funds for the Central Universities of Central South University, China
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DOI: 10.1016/S1003-6326(17)60183-3

dynamic stress rate method with the rule of blasting vibration attenuation have been summarized [5−7].

Split Hopkinson pressure bar (SHPB) system has been extensively used in dynamic properties research of rock and concrete material [8−10]. By using the SHBP system, KUMAR [11] and RINEHART [12] found out that dynamic strength of rock increased with the increase of strain rate. XIAO and ZHANG [13] noticed that the growth rate of compressive strength and the critical strain both had linear relationship with strain rate when strain rates ranged from 1.0×10^{-5} to 1.0×10^{-2} s^{-1}. BISCHOFF and PERRY [14] carried out the uniaxial compression test on concrete under strain rates of 5 to 10 s^{-1}, and the results proved that dynamic strength of concrete was 50% to 60% higher compared with static strength. OLSSON [15] found out that the growth rate of dynamic compressive strength of tuff was enlarged significantly under certain strain rate. In addition, SHPB system can also provide dynamic load on backfill specimens with strain rates of 10 to 90 s^{-1} to simulate the vibration caused by working equipment and blasting [16,17]. Furthermore, TEDESCO and ROSS [18] summarized the empirical formula of determining dynamic strength augment by synthesizing both the static and dynamic compression tests on concrete, and the formula indicates that dynamic strength of concrete increased rapidly when strain rate was over 63.1 s^{-1}.

Nevertheless, all the researches mentioned above are mostly about the dynamic mechanical properties of concrete and rock, research on dynamic mechanical properties of layered backfill is completely scarce. Consequently, to eliminate the gap and provide a theory basis of stability analysis of layered backfill under dynamic disturbance, researches on such area are extremely urgent. In this work, layered backfill specimen (LBS) was made and impact test on these specimens by using SHPB system was conducted. Furthermore, a cylindrical finite element model was constructed to simulate the stress and displacement status of LBS by the application of Flac3D. Analysis of micro-mechanism of LBS by scanning electron microscopy (SEM) was used to interpret the macro-dynamic mechanism of layered backfill.

2 Experimental

2.1 Material

The tailing materials were derived from SIM, Hebei, China, an iron mine with ultra-large production capacity. To obtain representative material samples for test, ingredient tailings were homogeneously mixed on the basis of the corresponding yields.

Particle size distribution was determined by Mastersizer−3000 laser particle analyzer, and the results are tabulated in Table 1. Cumulative mass fraction of particles whose sizes are small than 75 μm is 83.0% and the median size is 0.019 mm, relatively small, large amounts of fine particles will distinctly impair the strength of backfill body. Based on the compression test, compression coefficient and compression modulus of tested tailings were identified under varying loadings, the results are listed in Table 2. When load ranges from 100 to 200 kPa, the compression coefficient is about 0.83 and corresponding compression modulus is 2.90 MPa, the tailings present comparatively high compressibility.

Table 1 Particle size distribution of tailings

Size/μm	Distribution/%
500	7.6
250−500	6.8
75−250	2.6
50−75	6.1
5−50	63.2
<5	13.7
D_{50}	19

D_{50} is median size.

Table 2 Compressibility coefficient and compression modulus of tailings

Loading/kPa	Compressibility coefficient	Compression modulus/MPa
0−50	5.40	0.44
50−100	1.10	2.22
100−200	0.83	2.90
200−400	0.38	6.34

2.2 Fabrication of layered backfill specimen

LBS is a combination of at least two layers of backfill specimens with different characteristics. In this work, as shown in Fig. 1, two-layered LBS was adopted.

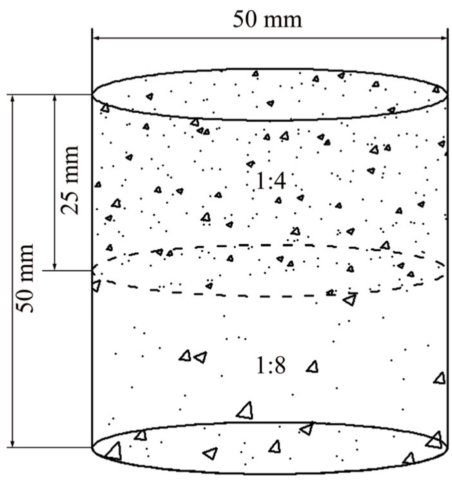

Fig. 1 Schematic diagram of LBS