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Analysis of concrete meso damage based on CT

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Abstract. CT is one of the effective means to analyze concrete meso-damage. Based on CT image under uniaxial compression, this paper used Amira—three-dimensional reconstruction software to segment the images, extract pores, count and calculate the pore volume .This paper analyzed the corresponding relation between pressure —pore volume diagram and pressure—displacement diagram under cyclic loading. The results showed that: under uniaxial loading condition, pore volume change can be used to describe the change of the meso pore of the concrete specimen, including compaction, initiation, extension and perforation.

1 Introduction

Concrete is a kind of complex artificial composite materials. The long-term practice [1-3] showed that the macroscopic failure of concrete under external loads included pore initiation, propagation and coalescence. Therefore, if you want to find the relationship of concrete meso-damage and macro mechanical properties, the first thing was how to descry the damage process of concrete with feature of concrete meso. Computer tomography technology also known as the CT, CT experiments on concrete material non-destructive detection and real-time observation of changes of concrete crack had unique advantage. Academician Chen Hou-qun [4] completed real-time scanned observation on concrete meso-damage under uniaxial compression using CT, and obtained the initiation, propagation and coalescence of the whole process of CT image of internal micro cracks of concrete; Wu Li-qin [5] put CT number cross section as the characteristics of representative failure of materials, from the angle of CT number to described the failure process of concrete internal. Liu Han-kun [6] did 3D reconstruction of CT images by using MIMICS software, a three-dimensional geometric model of concrete, and used Abaqus finite element software to complete the numerical simulation analysis, finally achieved good results. Liang Xinyu, Dang FA ning [7] based on changes of the average CT number of CT image in concrete meso damage process, put forward the concrete damage variable based on CT number, which showed that concrete specimens under uniaxial compression experienced elastic compression, CT scale crack initiation, crack propagation and coalescence, straight to the macroscopic failure of concrete. Zhou Huoming, Yang Yu and other [8] using acoustic emission location technology and CT image, based on acoustic emission positioning and section CT number variations of rock under uniaxial compression , crack of rock failure process was studied. Yu Aiping, Zhao Yanlin, Feng Yifeng[9] studied the failure process of bonding steel reinforced concrete by using acoustic emission instrument to real-time locate tracking corrosion in the pull-out test. Liu Jinghong [10] studied the fractal dimension of acoustic emission parameters of coal rock under uniaxial compression by using the fractal theory, and the correlation dimension of the acoustic emission energy decreasing continuously is seen as the precursor to instability failure of coal and rock. Raymond Lam, Li Shulinand other [11] according to the number of acoustic emission and the stress level of damage variable, the probability density function about acoustic emission number was proposed, and fitted of the linear relationship between the number of damage variable and acoustic emission number through the curve. Amira[12] is a 3D modeling software system, and it not only can achieve reconstructed using CT image, but also it can precisely statistic each composition material volume. this paper, based on the Amira software, extracted the crack of concrete test block under different loading stages, counted the crack volume, and got the change curve about pore volume and pressure, finally discussed the concrete meso-damage process.

2 CT experiment and pore volume statistics

2.1 The test specimen preparation

In the test of concrete specimens with information such as shown in table 1.

Table 1. The mix of concrete' in the test

material Amount of per cubic concrete			
Cement/kg	Water/kg	Sand/kg	Gravel/kg

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327	189	5	75	1133

2.2 Scanning device

CT detection system in the test is ACTIS300-320/225X from the State Key laboratory in China University of Mining & Technology (Beijing) [13], and the image size in pixels is 500*500. The scanning thickness is 0.2mm. Moreover, the specimen specification is a cylinder with a radius of 50mm and a high of 190mm. The specimens were carried out in 6 stages of scanning, including the initial phase, as shown in Table 2.

Table 2. The load corresponding to the 6 scanning time of the specimen

The first scan	The second scan	The third scan	The Fourth scan	The fifth scan	The sixth scan
Not loaded (kn)	22.3% peak intensity(kn)	44.8% peak intensity(kn)	67.2% peak intensity(kn)	89.6% peak intensity(kn)	peak intensity (kn)
0	30	60	90	120	134

Schematic diagram of experimental system was as shown in Figure 1.

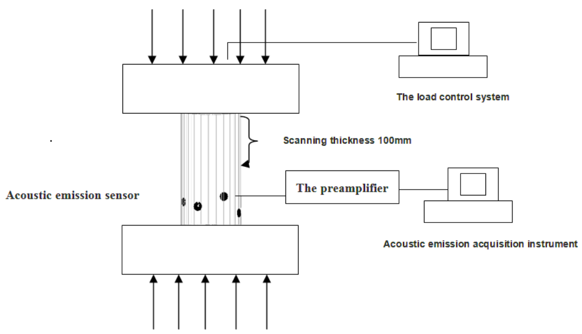

Figure 1. schematic diagram of experimental system

2.3 The result of the experiment

The specimen loading pressure- time curve was as shown in Figure 2.

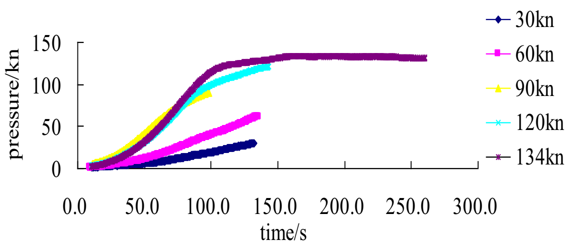

Figure 2 pressure displacement diagram

998 CT images were obtained. Select one section under different stress phase as shown in Figure 3.

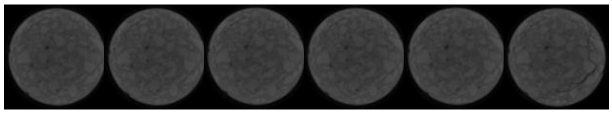

Fig.3 CT scanning image of the failure process of specimen und er uniaxial compression

There is no obvious changes and crackle in the first stages until the peak pressure.

The Amira software extracted the crack porosity as shown in Figure 4.

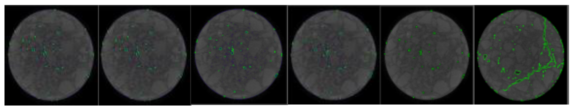

Figure 4: Pore threshold segmentation map

Concrete pore and crack is a green in figure 3, and pore crack changed more clearly than CT original images through the Amira software extracted pore crack. Based on the Amira software, the pore volume and the center coordinates of pore mass were counted in in different loading stages, as shown in table 3.

Table 3 :The pore volume and center coordinate of pore crack mass in different loading stages

Pressure(kn)	Pore volume (mm³)	center X	center Y	center Z
0	9799	62.4041	60.626	43.4224
30	10226	61.4252	61.6619	43.1364
60	11064	61.5649	61.7208	42.5127
90	11363	64.2467	64.466	42.8057
120	11716	67.6892	63.9985	40.7038
134	18629	83.5398	61.8019	40.505

The ordinate of the concrete test block ranged from (0 , 0 , 0) to (125 , 125 , 91) . From the table above, the center of mass coordinates for the initial pore in the concrete test block was (62.4, 60.6, 43.4) when the pressure was 0 KN. Thus, we can conclude that the initial center of mass coordinate in the concrete test block is uniform. After the destruction of the concrete test block, the center of mass coordinate in the concrete test block was (83.5, 61.8, 40.5). Compared with the center of mass coordinate for the initial pore in the concrete test block, the Y and Z coordinates almost didn't change, and the change of the X coordinate was more obvious. Generally speaking, the two showed some correlation. There was almost no change for the coordinate Z of the center coordinate form the beginning to the final failure for instability, thus, a conclusion can be made that the failure section is through, and this is the same with the spatial shape of the crack in the concrete test block from the CT images. As for the X , Y coordinates , with the enlargement of the external load , the center of mass coordinate in the concrete test block increased at the same time , furthermore , it expanse toward , and this agree with the idea that the two main cracks appear at the edge of the specimens . Draw a cure of "pore volume-stress" for the specimens based on the pore volumes in different stress stages from the above table, as figure 5.

Due to the high porosity of the specimen, namely, the severity of the initial damage, on the phrase of 30% ultimate stress, there was no obvious elastic compression for the test blocks on the whole, instead, the volume increased slightly. This is because of the severity of the damage, then the test blocks find a faster energy release methods, and it makes the elastic compression phrase shorter than before, accelerates the specimen into the stage of stable crack extension, and finally the pore volume increase slowly. When approach the limit stress, the test blocks enter the crack unable development stage, and the pore volume increases suddenly, finally the blocks fails for the instability.

3 Acoustic emission experiments

DS2 series full information of acoustic emission signal a nalyzed to complete the AE data acquisition of the whol e loading process. The relevant acoustic emission parame ter setting, threshold values of 100dB, PDT: 150us, HDT: 300us, HLT: 500us. The related technical indicators: 8 c hannel 3MHZ, sampling rate, data collection methods: 4 channel synchronous data acquisition, RS-35C integrate d front sensor: amplifier gain: 100 times.

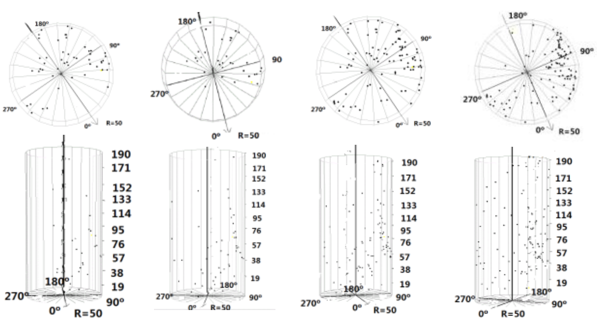

Figure 5: concrete specimens AE damage location map under the loading process of different stage of stress

Compared the damage localization maps on different phrase with the corresponding CT images, obvious cracks can be found only in the final failure stage with CT images. Compared with CT technology , the Acoustic emission instrument is more sensitive than former in damage localization , for instance , on the phrase of 23% ultimate press , one main crack appeared ,which indicates that the Acoustic emission instrument can track the damage localization of the concrete earlier , at the same time ,it approves the conclusion that the test blocks find a faster energy release methods , and it makes the elastic phrase shorter than before for the reason of its' severe initial damage .Through a comprehensive analysis from the damage maps with Acoustic emission instrument , load-pore volume diagram and load-time curve ,we can conclude that : ① in the early stage that the load was lower than the ultimate stress , the damage localization was disordered , the damage variable of the concrete is relative small , and the initial pore volume increases slighted ; in the cyclic load-time curve , the second loading curve deviates from the first loading curve , indicating that the blocks has experienced pore compression ,and step into the phrase of stable crack extension in advance ; part of the damage localizations overlap with the distribution of the initial pore , the discreteness of the damage localization is relevant with the randomness of initial damage ; ② when the load pass the 30% of the ultimate load , load-time curve increase slowly , with the incensement of the load , damage localization distribute around the final failure surface gradually and orderly , and the damage variable of concrete increase gradually ; load-pore volume curve increase slowly , from which we can see that pore distribution showed no obvious changes , and the center of mass coordinate in the concrete test block didn't change significantly , finally ,the blocks was in the phrase of stable crack extension ; ③ when the load approaches the ultimate load ---134KN , from the loading curve , the stress keep almost constant , while the strain increase sharply ; The damage localization points increase sharply in the final failure surface , and damage variable of concrete showed a significant incensement as well as the volume of pore crack ; the center of mass coordinate in the concrete test block changed obviously , and the blocks stepped into the phrase of instable crack extension , then the two main cracks appeared , which connected the failure surface caused by parts of the original pore , finally , the blocks failed in a instable way .

4 Conclusions

From the analyses above, we can conclude that:

Based on CT images, utilize Amira 3D visualization soft ware to complete pore segmentation, and count the pore v olume and the center of mass coordinate in the concrete t est block under different stress phrase. The conclusion sh ows that the changes of the former reflect the concrete tes t blocks experience three main deformation stages: the ela stic pore compression phrase, the phrase of stable crack e xtension, the phrase of instable crack extension. The cent er of mass coordinate in the concrete test block under diff erent phrase have certain correlation with the destruction process of the concrete test blocks. After the the destructi on of the concrete test block , the center of mass coordinate in the concrete test block is close to the initial center of mass coordinate in the concrete test block , this provide a theoretical basis for the pore structure of concrete in detection of weak surface and in reinforcement in the future . As for whether the distribution of pore in concrete have a decisive influence on the failure of concrete under uniaxial compression, it still calls for plenty of subsequent experiment to prove.

But by the limit of software, so image segmentation had not been a unified standard, and this paper also has the following shortcomings to be improved:

A) Automatic threshold segmentation has high requirements on the picture, but the manual segmentation is more subjectivity. the segmentation effect by using the method of combination of human and computer is improved, and the overall regularity is no problem, but the data accuracy will be affected, which is not conducive to the next quantitative analysis
B) amount of initial crack is differ from the statistical values, there may being reasons: measurement error; the pore distribution may also have an impact, because the pore volume of statistics is owned to the local block; the main reason is that Amira statistical software requirement for the volume of pore sealing, so the surrounding open pores or not closed pores in the test block will not be statistics, resulting that pore statistics is not comprehensive enough; Some micro pore was not extracted in the process.

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