Failure Process Analysis of Brittle Specimen with an Open-hole under Compression

Nagasaki University **Student Member** Cheng Zhao **Member** Hiroshi Matsuda
Student Member Hayato Kozuma **Fellow** Tsutomo Yamashita

1. INTRODUCTION

Rock failure phenomena have been exhaustibly investigated in the past few decades both in the laboratory and the field. Lockner et al. [1], in their test the AE (acoustic emission) technique has been used to monitor the AE event locations showing the fault growth in various kinds of rock or rock-like brittle samples. There are also many scholars brought special interest to the study of numerical method to simulate the fault nucleation based on the rock interaction. In present research, artificial material was used in order to obtain uniform specimens which can be used to assess the effects with regard to the pre-existing defects. Because in present methods to obtain the inside crack paths are not so accurate or acceptable, by using the plate specimen, secondary cracks can easily occur and develop on the surface of specimens, moreover took our measurement method into consideration plate specimen was chosen. Digital Image Correlation Method which is a full-field and non-contact measurement was employed in this research to observe the failure process in details and make a record of the surface displacement during the compression. Numerical process simulation were also carried out, the investigation found that there are good correlations between experimental and numerical values. The conclusions obtained by the experimental methods and numerical simulations are compared and discussed in this paper.

2. EXPERIMENTAL INVESTIGATION

The interpretation of results of experimental investigation on real rock is usually complicated by sample variability [2]. In order to overcome this difficulty, laboratory specimens were made from an mixture of plaster, water and retardant in a weight ratio of 1:0.2:0.005 was used to describe soft rock. Parameters of specimen are shown in Table.1 and schematic of compression test are shown in Fig.1

Table.1: Specimens` parameter

a×b×c	σ_c	σ_t	E_S	ν
mm	MPa			
100×100×10	47.4	2.5	28700	0.23

Digital Image Correlation Method (DICM) has been developed and used to measure deformation and strains of materials under various loading regimes with sub-pixel accuracy since the 1980's. It has been successfully applied to determine strains in specimens of solid and applied to a wide range of experiments.

By using this measurement, uniaxial compression test was carried out on the artificial rock-like specimens with an open hole. In fact a series of specimens were tested, the radius of open-hole increased from 5mm to 40mm at a step of every 5mm.

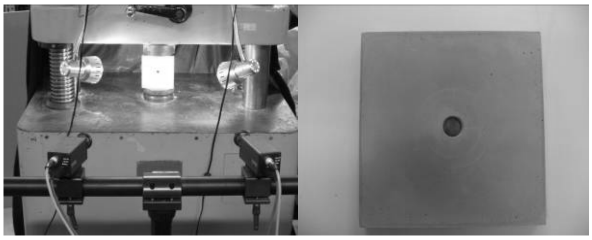

Fig.1 Schematic of compression test by using DICM and specimen with an open-hole

Due to the limitation of textual length, the strain contours of $a = 20$mm obtained by DICM are listed , this specimen failed at step 721, the final failure type agree well with the strain process analysis. Counter figures shows us the crack started from the edge of pre-existing defect, according to the theoretical analysis, split crack would be obtain. However due to the boundary effect, they develop in the shear zones till failure. Details are shown in Fig.2.

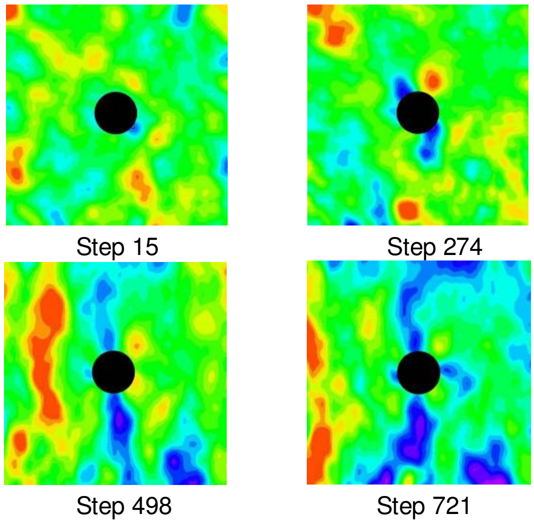

Fig.2 DICM strain contours during the test process

In order to compare the experimental conclusions, numerical simulations are also carried out.

3. NUMERICAL SIMULATION

In this study, Realistic Failure Process Analysis code (RFPA^{2D}) is employed. Finite element technique is used in this code. The package can handle brittle material with heterogeneous material properties, can perform non-liner deformation analysis, which includes

Keywords: *Brittle materials, Failure process, Full-field, DICM, Numerical*
Email: d707111k@cc.nagasaki-u.ac.jp

the occurrence and development of cracks and fractures. It is a progressive damage model, which can simulate the deformation, stress distribution and failure induced stress redistribution, furthermore fracture initiation and propagation in heterogeneous materials can also be done.

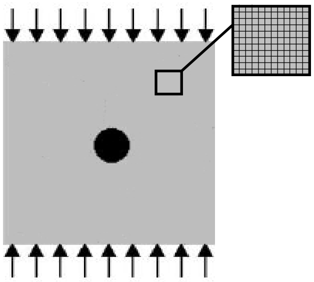

Fig.3 Schematic diagram of numerical simulation

As it is shown in Fig.3, the numerical specimens subjected to uniaxial compression. The specimen is set as a mesh that consists of 100×100 elements (Fig. 3). RFPA^{2D} was then used to simulate the failure process by applying a total of 180 load steps. Initially a load step of 1kN per step was applied up to 100 steps. There after a strain controlled load of about 0.001 mm per step was applied until total failure occurred.

As to the brittle materials, Mohr-Coulomb criterion has a limit on the description of tension strength. A modified coulomb failure criterion was employed in this numerical simulation. It includes tension cutoff and the tension flow rule is well associated. For details of this criterion please see, for example, Chen and Han [3].

The fracture process is shown in Fig.4 as an example of this numerical simulation. In which the peak strength is 50MPa (step151), just after that the sample fractured totally. It can be seen buckling occurs when the cracks reach the two ends of the specimen, which failure by starting a new crack in shear zones around the pre-existing open-hole. The failure mode shows that the specimen containing the smaller hole fails by cracks initiated in a shear zone connecting the hole and the surface, due to the proximity of the hole to the boundary. This failure is found to be caused by the following sequence. At first the cracks grow fast, and then, when the tips of the cracks near the ends of the specimen, the propagation slows down, or sometimes stops, due to the boundary effect.

It is worthwhile to note that this result differs from the theoretical prediction for a hole in an infinite domain, the theoretical failure follows the split failure model. One probable reason for such differences may be due to the interaction between the growing cracks and boundary conditions, which appears to retard the crack growth as the crack is approaching the end surfaces. And, thus, the shear cracks zones are more likely to develop. That means for the brittle specimens, if the shear stress in the area between the hole and the free boundary of the specimen is high enough, shear failure will occur between the hole and free boundary.

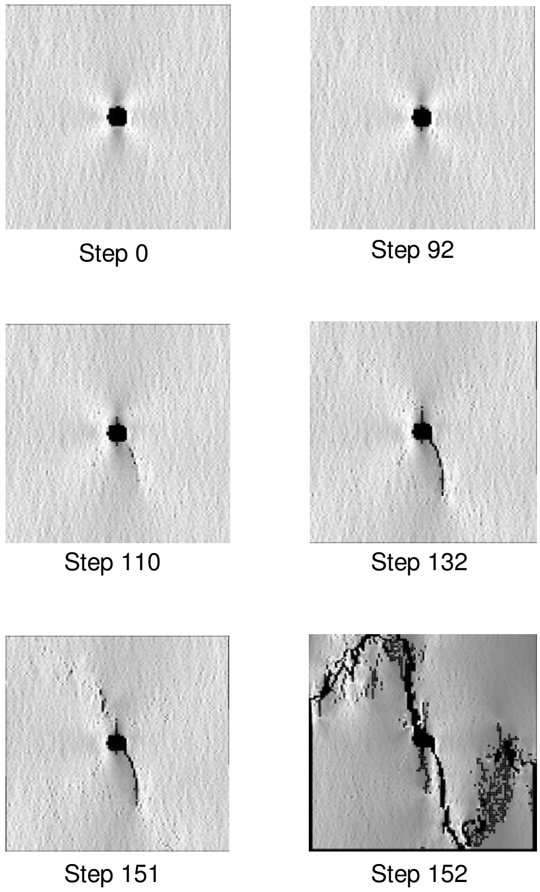

Fig.4 Numerical simulation of failure process

4. CONCLUSION

Based on the experimental and numerical investigations, it is obtained that: during the failure process of brittle materials with pre-existing hole defect, the secondary cracks occur from the open-hole which agree with the theoretical analysis. However due to the boundary effect, they develop in the shear zones till failure. Therefore shear fracture model is obtained in the process simulation

REFERENCES

[1] C. A. Tang, and R. H. C. Wong: Modeling of compression – induced splitting failure in heterogeneous brittle porous solids. Engineering fracture mechanics. Vol. 72, pp.597-615. 2005

[2] Y. Jiang and J. Xiao: Development of an automated servo-controlled direct shear apparatus applying a constant normal stiffness condition. International journal of rock mechanics and mining sciences. Vol.41(2) pp.257-286. 2004

[12] W. F. Chen, and D. J. Han: Plasticity for Structural Engineers. New York. Springers-verlag. 1988