Using webcam to visually observe the mechanical behaviors of Shirahama sandstone under triaxial compression

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ABSTRACT: We present a newly developed monitoring system to directly visually observe the shear behavior of Shirahama sandstones under triaxial compression testing. The proposed visual monitoring system contains a commercially available webcam and a pressure-resistant steel housing device. The webcam records the video clip of the rock specimen surface during the triaxial compression test. The recorded video frames and their associated digital image correlation (DIC) results allow a better understanding of the evolution of the strain fields and fracture development. The implementation of the proposed monitoring system is simple, safe, and inexpensive, but allow new data to be measure and provides new insights into the progressive shear behavior under triaxial compression loads.

Keywords: webcam, visual monitoring system, triaxial compression test, DIC, sandstone.

1 INTRODUCTION

Triaxial compression testing of rock samples provides fundamental information for understanding the deformation and fracture behavior of rock mass, which is related to underground engineering applications such as tunneling, nuclear waste disposal, and carbon dioxide sequestration. Triaxial compression tests have been widely conducted and are widely accepted as a reliable test method and measurement system because of their simplicity, robustness, and repeatability (ISRM 1983; Paterson and Wong 2005). However, in general, triaxial compression test of rock samples are performed in the steel pressure vessel, and it is difficult to visually capture and observe the behavior of rocks, as in uniaxial compression tests.

We recently developed a new measurement system to directly visually observe the behavior of rock specimens from the inside of the pressure vessel of the triaxial test apparatus. This newly developed measurement system exhibited three primary advantages compared to the other conventional measurement system: (i) the measurement system allows direct observation of the mechanical behavior of the rock specimen from inside the pressure vessel under confining pressure, (ii) the measurement system is inexpensive. It requires only a commercially available digital camera and the simple steel housing, and (iii) the measurement system is safe and can be installed without any modification of the existing triaxial apparatus.

The purpose of this study is to visually observe the progressive mechanical behavior, including fracture developments, of Shirahama sandstone samples under triaxial loading. The recorded video frames and their associated digital image correlation (DIC) results allow a better understanding of the evolution of the strain fields and fracture development.

2 EXPERIMENTAL PROCEDURE

2.1 Visual monitoring system in pressure vessel

The proposed visual monitoring system is a modification of the digital camera measurement system developed by the authors to the webcam. Figure 1 shows a schematic diagram of the webcam visual monitoring system in the pressure vessel used in the triaxial compression test. The webcam is placed in a steel pressure-resistant housing, which is then placed inside the pressure vessel for monitoring the mechanical behavior of the rock specimen. Figure 2a shows a commercially available webcam product used for visual observation. To make effective use of the limited space inside the pressure vessel, the webcam was dismantled and only the printed circuit board and lens are used (Figure 2b). Figure 2c shows the dismantled webcam device inside the steel housing (41 mm × 70 mm × 20 mm). The steel housing is a simple structure made by SUS304 stainless steel and polycarbonate plate for a viewing window. Since the housing is under pressure during the experiment, the gap between the polycarbonate plate and steel as well as the line feed through must be properly sealed. For this purpose, we used the rubber O-ring and the tapered outlet with a resin adhesive.

The change from a digital camera to webcam make the following points possible. Based on the specifications and battery capacity of a commercially available digital camera, it can record only two 30-minute video clips. However, they are usually insufficient to record the entire experiment; the webcam can take video clip as long as digital storage allows without worrying about the battery. In addition, the smaller size of the webcam allows the housing to be smaller, and therefore the pressure capacity to the confining pressure can be increased.

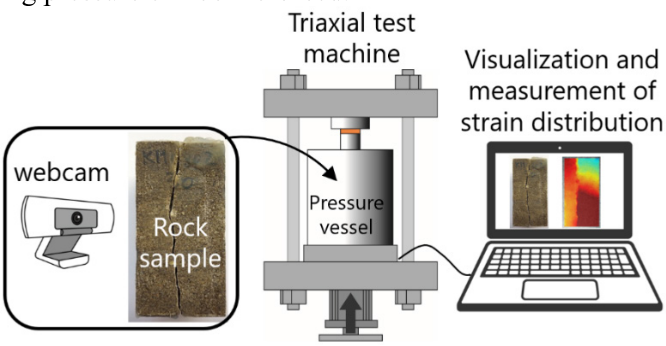
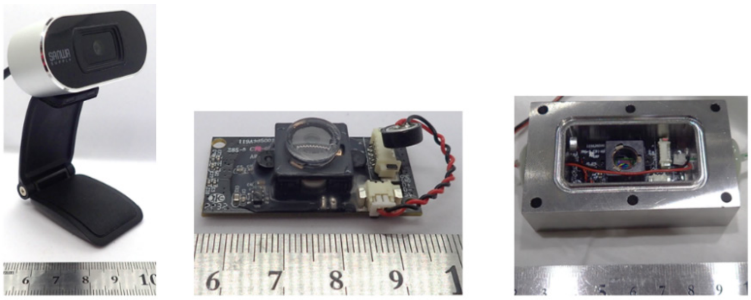


Figure 1. Illustration of the webcam visualization monitoring system in pressure vessel.



(a) (b) (c)

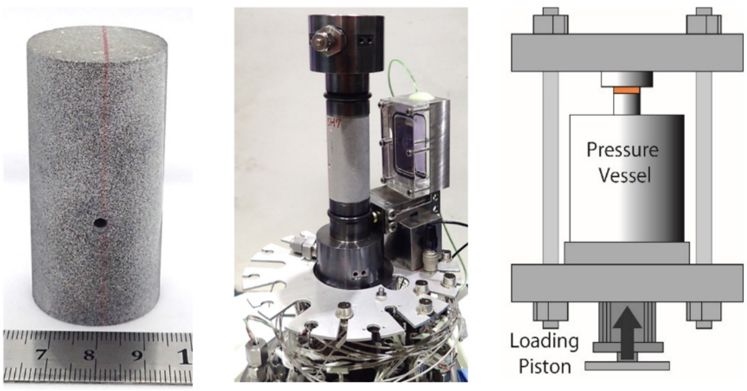
Figure 2. The webcam used in this study: (a) webcam product, (b) dismantled printed circuit board and lens of the webcam, (c) dismantled webcam device inside the steel housing.

2.2 Experimental setup

The triaxial test apparatus at the Geological Survey of Japan, Ibaraki, Japan, is used to conduct the triaxial compression tests of the rock samples. Various studies on the mechanical and hydraulic behavior of rock samples have been conducted with this apparatus. Additional details can be found elsewhere (Asahina et al. 2019). The experiments of this study followed the procedure for a conventional triaxial test but with the addition of the proposed monitoring system (Figure 3b). Specimens are loaded axially at a rate of 0.04 mm/min after the confining pressure is applied in the pressure vessel. To measure the deformation, two LDTs with an accuracy of ±1.0 μm were mounted in the axial direction and two in the radial direction.

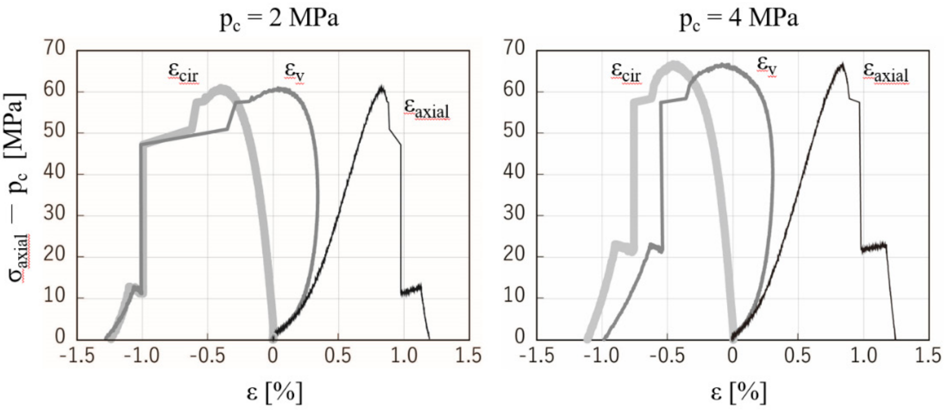
Table 1. Summary of material properties of Shirahama sandstone.

Property	Unit	Value
Uniaxial compressive strength	MPa	77.5
Young's modulus	GPa	15.3
Poisson's ratio	-	0.27
Cohesive strength	MPa	21.8
Internal friction angle	°	37.5



(a) (b) (c)

Figure 3. (a) Photo of Shirahama sandstone (30 mm diameter and 60 mm length) with a 1mm hole at the middle height. (b) Photo of the assembly, showing the steel housing with the dismantled webcam inside, the end-loading plugs, and the Shirahama sandstone specimen. (c) Schematic representation of the triaxial apparatus, showing the vertical loading piston and pressure vessel.



(a) (b)

Figure 4. Stress–strain curves of specimens under different confining pressures: (a) 2 MPa, (b) 4 MPa. Note that strains are measure by LDTs.

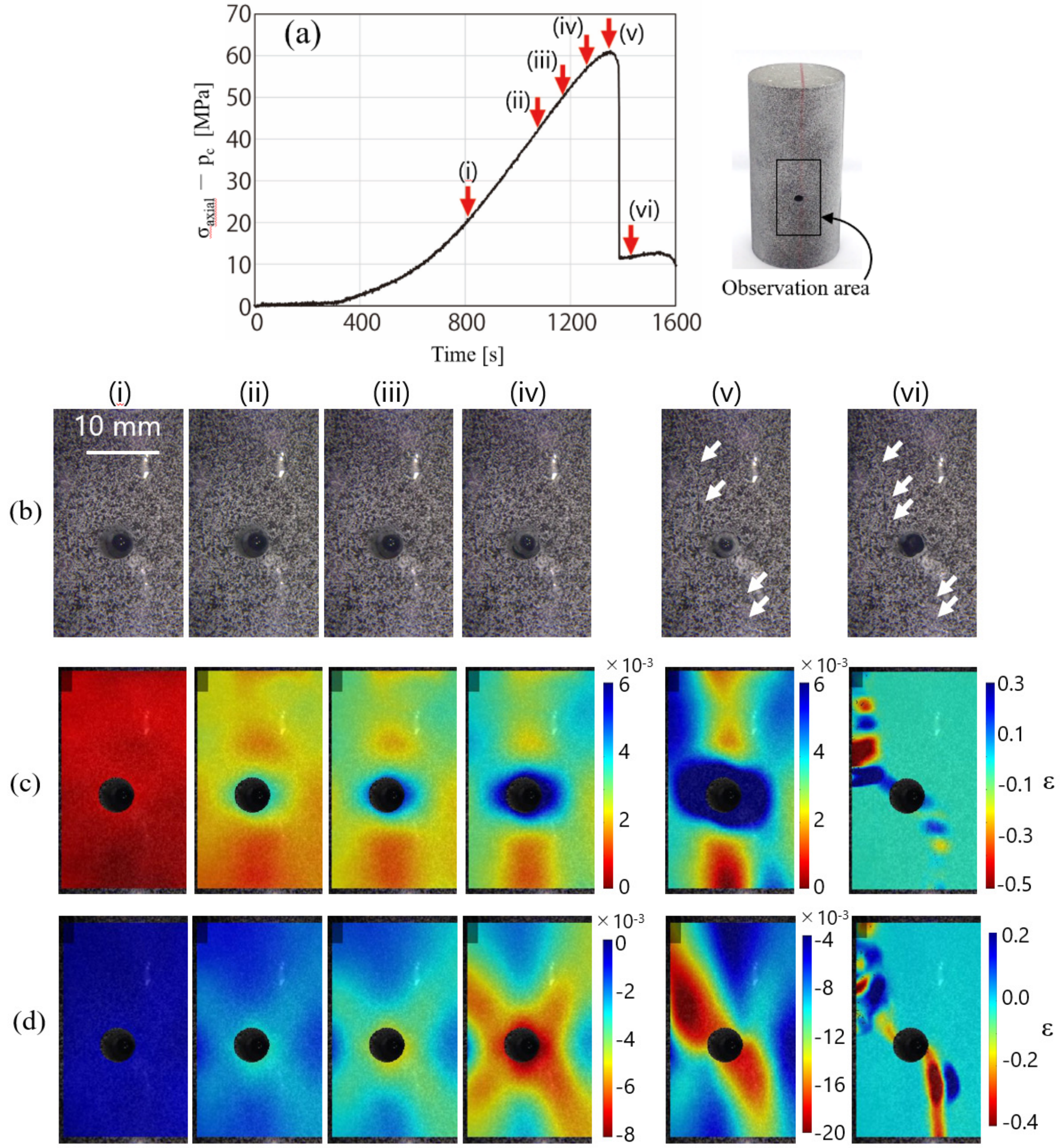


Figure 5. Progressive compressive behavior of the specimen with Pc = 2MPa: (a) evolution of differential stress. The timings from (i) to (iv) of the successive frames are shown by red arrows. (b) video frames. The scale shown in the first video frame. (c) vertical strain fields. (d) lateral strain fields. Note that positive is compression and negative is tension. Also note that the different color scales are used in the later stages.

3 RESULTS

Figure 4 shows the stress–strain curves for two specimens under different confining pressures, p_c. In this figure, the horizontal axis shows the strain in axial and circumference directions, ε_{axial} and ε_{cir}, as well as the volumetric strain, ε_V, while the vertical axis shows the differential stress ($\sigma_{axial} - p_c$). The two specimens are referred to as SS2, SS4 for the confining pressure 2, 4 MPa, respectively. The peak strength clearly shows the effect of the confining pressure. The shapes of the stress-strain curves are similar for two specimens. The initial stage of the curves exhibits hardening behavior that is typically associated with the nonlinear contact conditions and a slight contraction caused by the closure of defects inside the specimen. The curves become linear in the elastic condition. After reaching the peak stress, the stress decreases slightly, then decreases sharply, and then stabilizes at the residual strength.

Figure 5 shows the video frames of SS2 captured by the proposed monitoring system during loading, along with the corresponding vertical and lateral strain fields (Figure 5c and 5d). The corresponding stress-strain conditions are also indicated by red arrows on the stress-strain curve (Figure 5a). The stages from (i) to (iv) is the pre-peak stress stage, whereas (v) is the peak stress and (vi) is the post-peak stress stage. In the video frames taken during the experiment (Figure 5b), it is difficult to recognize the changes in the stages (i) through (iv), but the later stages (v) and (vi) show the diagonal cracks branching out from the hole as indicated by white arrows. We can also observe that the hole is crushed by compression (Figure 5b-(vi)). On the other hand, the strain field measurement results capture the changes from the early stages. Both vertical and lateral strain fields are largely changed during the transition from (iv) to (v). In the pre-peak stages from (i) through (iv), the strain is relatively symmetrical, whereas in the stages (v) and (vi), the large strain confliction can observe in the diagonal direction from the upper left to the lower right. The progressive change in the vertical strain field shows that the deformation around the hole increases with compressive strain (Figure 5c). On the other hand, the progressive change in the lateral strain field indicates that tensile strain is generated diagonally from the hole, and that the tensile strain on one side increased, leading to failure.

4 CONCLUSION

In this study, we used the webcam to capture the mechanical behavior of Shirahama sandstone under triaxial compression loadings. The captured video frames show the progressive strain fields and fracture development which have not been able to observe by the conventional measurement system. The proposed monitoring system is simple, safe, and inexpensive, but provides detail information inside the pressure vessel under confining pressure. We plan to apply this monitoring system to the study of the hydraulic responses under fracture development. Currently, we are conducting the lab experiment to directly observe the relationship between the change in roughness of rock samples due to shear and the change in hydraulic properties.

REFERENCES

Asahina D, Pan P-Z, Sato M, Takeda M, Takahashi M. 2019. Hydraulic and Mechanical Responses of Porous Sandstone During Pore Pressure-Induced Reactivation of Fracture Planes: An Experimental Study. Rock Mechanics and Rock Engineering. 52, 1645-1656.

ISRM, 1983, Suggested methods for determining the strength of rock materials in triaxial compression: Revised version: International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, v. 20, no. 6, p. 285-290.

Paterson, M. S., and Wong, T.-f., 2005, Experimental Rock Deformation - The Brittle Field, Sprng Sc. & Business Media.