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Evaluation of Fracture Process of a Polymer Gel Using a Non-contact Acoustic Emission Method

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Abstract

Polymer gels have been actively used in many products. They have not only been used as materials for mechanical components, but also for contact lenses and jelly-like food. It is important to identify the fracture mechanism of these gels. This study aims to develop a method for monitoring the fracture process via acoustic emission (AE) testing. AE methods were first employed to monitor the fracture process of agar gel during a compression test. The AE signals were measured by water-coupled and air-coupled methods, and the results obtained were compared. The water-coupled method, agar gel was immersed into purified water and employed conventional contact-type AE sensors which were set along the side wall of the glass container. In air-coupled method, non-contact type ultrasonic transducers which were set on opposite sides of the gel at a distance of 20 mm from the surface of the gel. Using these methods, AE signals were detected at syneresis and internal crack initiation during the compression fracture process. The characteristics of AE generation were then compared. The water-coupled method detected the AE signals in each process. The amplitudes of AE signals due to syneresis were weak. The air-coupled method detected the AE only during syneresis because the detectable frequency range of the sensors was unsuitable for the internal cracking process.

Keywords: Polymer gel, Acoustic emission, Large deformation, Fracture, Non-contact measurement, Air-coupled ultrasonic method

1. Introduction

Polymer gels have been actively used in many products [1]. They have not only been utilized in mechanical components but also in contact lenses and jelly-like food because the components of polymer gels are molecular chains and solvating media. As a result, the structures are characterized by "viscoelasticity", "a low elastic modulus compared to metals and ceramics" and "a non-linear relationship between power and deformation". In order to apply these materials to form products, it is important to identify their mechanical properties and fracture process.

he acoustic emission (AE) method is a nondestructive evaluation technique for monitoring crack initiation and propagation behavior via detection of elastic waves generated by the rapid release of strain energy within deformed materials. The AE method is generally employed to evaluate the fracture process in metallic and composite materials. Although, a contact-type piezoelectric transducer is generally used in AE monitoring, there is a problem of interference with deformation by the AE sensor during the fracture process owing to the large deformation in case of polymer gel.

In this study, the AE method was employed to monitor the fracture process in a polymer gel by using the water and air-coupled methods for a non-contact AE, which did not affected the large deformation. By using these methods, we estimated the mechanism of AE generation. Furthermore, the relationship between the AE parameter and compression rate was also studied.

2. Experimental

2.1 Material and specimen

We used agar gels of concentrations is 2.0, 3.0, 4.0 and 5.0 wt.%. The agar gel is formed by mixing agar powder and purified water and then, swelled in water at room temperature for 1 h, preheated between 333 and 343 K, heated between 368 and 373 K, poured into a cylindrical container (diameter 30 mm, height 35 mm), cooled slowly at room temperature for 1 h, and further cooled at 278 K for 24 h [2].

2.2 Experimental method

In this study, two types of AE monitoring techniques were used and compared. The experimental setup for air-coupled AE monitoring is shown in Fig.1. Figure 2 shows the AE measuring system for water-coupled method. The air-coupled method use non-contact type AE sensors (Ultran, NCG100 and NCG200), which are set at a distance of 20 mm from the surface of the gel at 120° intervals. In the water-coupled method, the polymer gel is immersed in the circular glass container with purified water. Conventional contact-type AE sensors (PAC, R3α, R6α, R15α and S9208) are used, which are set along the side wall of the circular glass container. It can be seen from Fig.2 that R3α and S9208 are connected to digitizer A, while R6α and R15α are connected to

digitizer B. The propagation distance through the water, i.e., the distance of the detector plane of the sensor from the surface of specimen is 30 mm.

In each method, the AE signals are amplified by a pre-amplifier (40 dB, NF Corporation, 9913) and the specimen is set on sandpaper, which is attached to the jig and floor surface. Furthermore, we used the AE sensor which has difference resonance frequency to measure high sensitivity in wide range.

In this study, we employed air-coupled method to estimate the mechanism of AE generation during compression test and water-coupled method to comparison of compression rate and concentration in AE measurements. In each test, the agar gel and purified water are maintained at room air temperature (299 K). The compression rates applied are 0.5, 1.0, 3.0 and 10.0 mm/min.

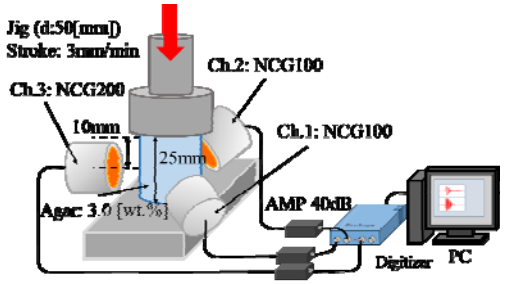

Fig. 1 Experimental setup for monitoring AE signals by the air-coupled method during the compression test

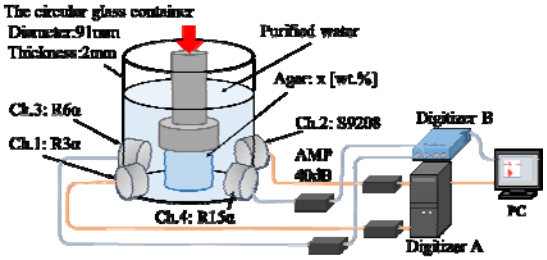

Fig. 2 Experimental setup for monitoring AE signals by the water-coupled method during the compression test.

3. Results and discussion

3.1 Mechanism of AE generation

Figure 3 shows the relationship between changing the compression load and cumulative AE events during the test. The dashed lines indicate the changing behavior of the fracture in the compression test. Figure 4 shows the photographs of the fracture process during the test. In Fig. 4(a), i.e., at the start of the test, the condition of the specimen surface is dry and it has no crack. At 25 s (in Fig. 4(b)), conceivable syneresis occurs. The specimen surface is wet and it is not cracked,; however, AE signals were detected in Ch.1 and Ch.2 (Fig. 3). This result indicates that the syneresis is related to the AE signals. The syneresis was caused by breaking of the molecular chains. At 138 s (in Fig. 4(c)), visible surface crack occurs. The condition of specimen surface is wet and fluid is present on the surface. Although, the visible crack is about 5 mm in, the AE signal was not detected. This is due to the operating range of the AE sensors.

From these results, we can confirm that the AE signals were caused by the fracture of the polymer gel structure, which is different from metallic materials, during the compression test.

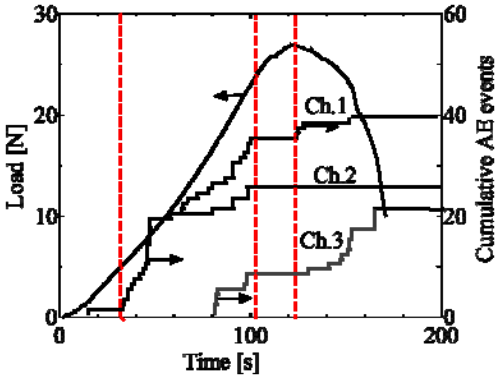

Fig. 3 Load-time curve and cumulative AE events diagram of 3.0% agar during the compression test by the air-coupled method.

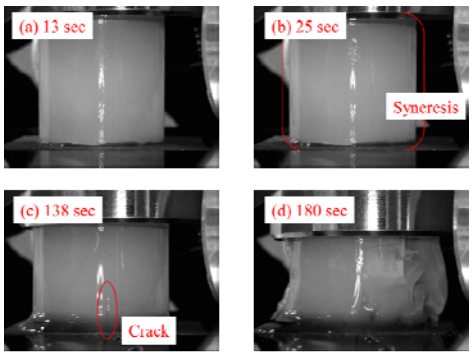

Fig. 4 Surface photographs of the specimen during the test at (a) 13 s, (b) 25 s, (c) 138 s and (d) 180 s.

3.2 Comparison of compression rate and concentration in AE measurements

Figure 5 shows the fracture load as a function of the concentration of agar gel at different compression rates (0.5, 1.0, 3.0 and 10.0 mm/min). Figure 6 shows the average variation in cumulative AE events during the internal cracking process versus the concentration of agar gel at each compression rate. In Fig.5, the fracture load increases with increasing concentration and compression rate. This trend is due to the increasing stiffness caused by the increasing molecular density and number of molecules in a given cross-section as a consequence of the molecular orientation [3]. In Fig. 6, the cumulative AE events increase with increasing compression rate. The reason for the increasing cumulative AE events is the increase in hardness of the specimen with the compression rate and concentration. Moreover, increasing hardness affects the strain energy and AE events. However, the

gradient for 2.0 wt.% is larger than those for other concentrations. The error could be due to the increasing syneresis caused by the higher percentage of water in the low concentration gel.

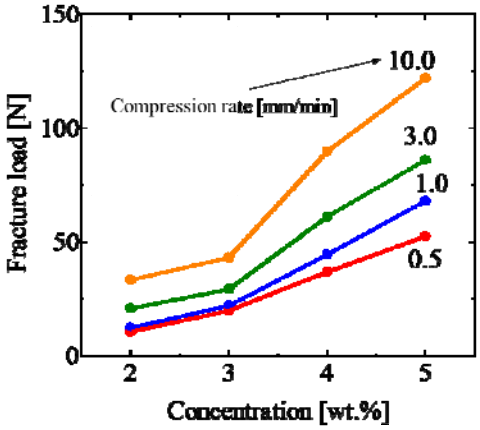

Fig. 5 Fracture load as a function of concentration of agar gel at various compression rates.

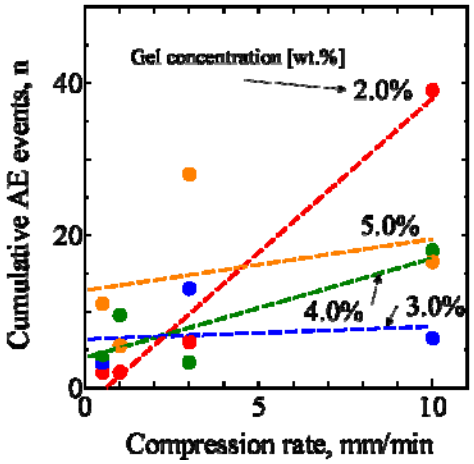

Fig. 6 Average variation in cumulative AE events during the internal cracking process versus concentration of agar gel at various compression rates.

From these results, it can be inferred that, the AE signals are approximately proportional to the compression rate and gel concentration.

4. Conclusion

In this study, we proved that the AE method can be applied to a polymer gel, whose structure is different from that of metallic materials, via detection of AE signals during syneresis and cracking. Moreover, we found confirm that the AE signals were dependent on the compression rate and gel concentration, by studying the relationship between cumulative AE signals during internal cracking and compression rate or gel concentration. These relationships suggest the possibility of measuring the properties of gels, e.g., the elasticity, and gel concentration, by using the AE method.

5. References

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