Evaluating the Effect of the Filler Amount on the Crack Growth Behavior of Natural Rubber and the Strain Distribution

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Abstract. This study evaluates the effect of the amount of the filler on the strain distribution in the vicinity of a crack in natural rubber (NR). In addition, the difference in crack growth behavior due to difference of the amount of the filler is also evaluated. For this purpose, a test is conducted on the rubber specimen with various amount of the filler containing the initial crack. Then, the images recorded with a high-speed camera are analysed by using digital image correlation (DIC). From this experiment, the relationship between tearing energy and crack growth rate is obtained. This result shows that the crack propagates very fast.

Introduction

Recently, there has been an increasing need for vehicles with less environmental impact in the automobile industry. Thus, the tire products are also required to have a low impact on the environment. The rubber material used in these products needs to have a long life, which is related to the rubber wear phenomenon.
Southern and Thomas[1] found that wear can be expressed by crack growth. In order to clarify the mechanism of this phenomenon, it is essential to consider crack growth. The tearing energy was introduced as a fracture mechanics parameter for elastomers by Rivlin and Thomas[2]. This theory is based on the energy balance of the entire system. To understand the essence of crack growth, stress-strain analysis at the crack tip is very significant. Recently, analysis of crack tips has been actively performed. However, it is still unclear how the amount of the filler affects the crack growth behavior.
Therefore, this study evaluates the effect of the filler on crack growth behavior and strain distribution of natural rubber by using digital image correlation (DIC).

Test method

Figure 1 shows a rubber specimen with a length of 30 mm, a width of 120 mm, and a thickness of 2 mm. The specimen is given 133 % strain in a tensile testing machine. Then, a crack of about 20 mm is inserted with scissors to make the crack run by itself. A random pattern is applied to the surface of the specimen to use DIC. The frame rate is 200 fps and the shutter speed is 25 μs. The recorded images are 1280 × 1024 pixels (8 bit), and 1 pixel ≈ 0.094 mm. The analysis region is shown in Figure 2. The subset size is 15×15 pixels and the strain window area is 21× 21 pixels.

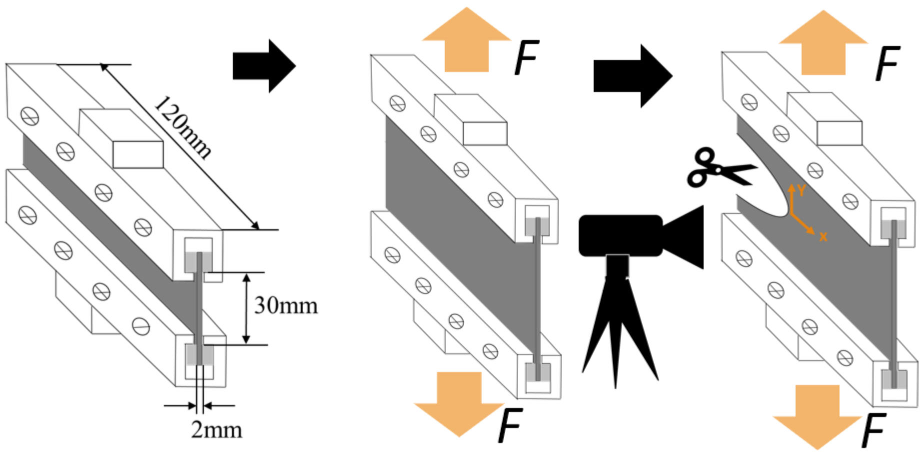

Fig. 1. Rubber specimen and how to experiment.

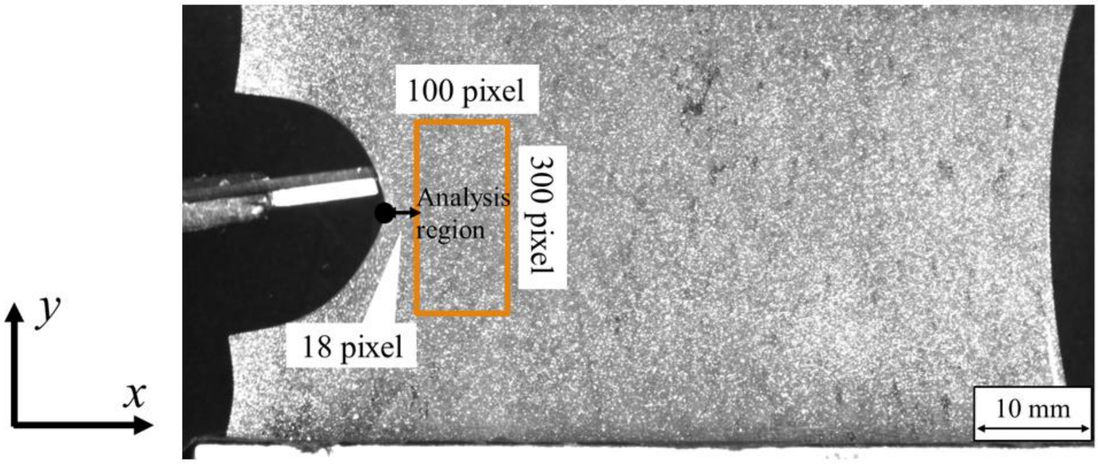

Fig. 2. Analysis region.

Results

It is shown the relationship between the tearing energy and the crack growth rate in Figure 3. The average rate V [m^2/s] divided by the elastic wave velocity C_s [m^2/s] is used as the crack growth rate on the ordinate. From Figure 3, it is found that the crack growth rate of all specimens is around 10^{-2} [-], which corresponds to the fast mode.

Figure 4 shows the *y*-direction strain distribution (Silica30), which is tensile direction. It is difficult to follow the random pattern due to the large deformation in the vicinity of the crack, so the analysis region is shown in Figure 2. From Figure 4, it is found that the strain has a large value as it approaches the crack tip.

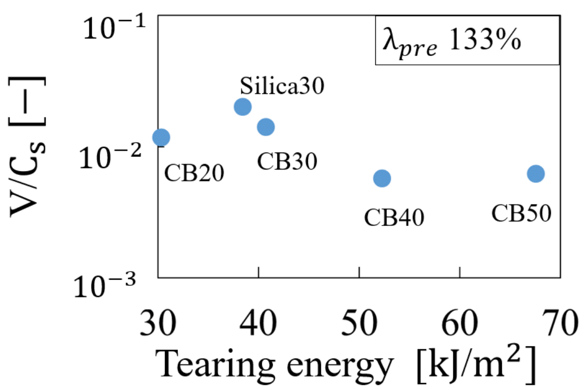

Fig. 3. Crack growth rate versus tearing energy.

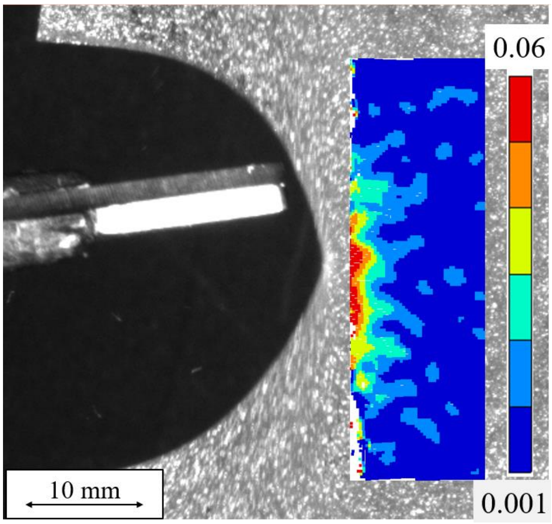

Fig. 4. Strain ε_y distribution (Silica30).

Conclusion

A test is conducted on the rubber specimen containing the initial crack to observe the crack growth behavior and the strain is calculated from the displacement obtained by DIC. In this experiment with 133% strain, it is found that the crack propagation is very fast. Even for the fast mode with large deformation, it is revealed that the strain concentration at the vicinity of the crack by DIC.

References

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