Evaluating the Effect of the Filler Amount on the Crack Growth Behavior of Rubber and the Strain Distribution in the Vicinity of a Crack

Hotaka Mitamura[1a], Keisuke Iizuka[1], Satoru Yoneyama[2]

[1a, 1,2] Department of Mechanical Engineering, Aoyama Gakuin University,

5-10-1 Fuchinobe, Sagamihara, Kanagawa, Japan,

[1a] c5621172@aoyama.jp

Abstract. This study evaluates the effect of the filler amount on the strain distribution in the vicinity of a crack. In addition, the difference in crack growth behavior due to difference of the amount of filler is also evaluated. For this purpose, the crack growth behavior is observed on rubber specimens with various amounts of the filler. Then, the images obtained with a high-speed camera are analyzed by using digital image correlation. The experimental result reveals the difference in the energy loss affects the tearing energy. In addition, the displacement and strain distributions show that the rubber material with a large energy loss uses the input energy for the crack opening rather than the crack growth, so the crack growth is slower.

Introduction

Recently, there has been an increasing need for vehicles with less environmental impact in the automobile industry. Therefore, the tire industry also demands fuel-efficient and high-performance tires. Tire products must be low-impact on the environment. The rubber material used in the above needs to have a long life, and the duration of life is related to the rubber wear phenomenon.
Southern and Thomas[1] found that wear was expressed by crack growth. In order to clarify the mechanism of the phenomenon, it is necessary to think about crack growth. Rivlin and Thomas[2] proposed tearing energy avoids dealing with the complex stress field at the crack tip and discusses only the energy balance of the system as a whole, including the crack. In this way, fracture mechanics of rubber have been developed by avoiding the handling with the stress field at the tip of the crack and dealing only with the energy balance of the entire system. To understand the essence of crack growth, stress-strain analysis at the crack tip is very important. Recently, analysis of crack tips has been actively performed, and as a previous study, from wide-angle X-ray diffuse diffraction crystallization by high-intensity synchrotron radiation by Rublon et al[3], the elongation crystallization behavior of the crack tip of natural rubber was observed. In that experiment, when the tearing energy and the volume of the stretched crystallized part at the crack tip are plotted for pure rubber and three-level carbon black (CB) -filled rubber, one master curve was obtained regardless of the CB filling amount. This indicated that the crack growth behavior was governed by the size of the stretched crystallization region at the crack tip rather than the CB filling amount. However, the relationship between the filling amount of other fillers such as silica and sulfur and the crack growth behavior has not been clarified.

Experiment

Specimen

Table 1 shows the physical properties of SG3907, SG3908, SG3909, SG4105, SG4106, SG3902 and SG4101, which are the specimens used in the test. A strip-shaped specimen with a length of 28 mm, a width of 175 mm, and a thickness of 0.6 mm as shown in Fig. 1 is stretched by 75% with a tensile test machine. Next, a crack of about 10 mm is made with scissors and the crack is self-propelled. In addition, A random pattern is applied to the surface of the specimen in order to use the image correlation method.

Table 1. Physical property values.

Sample Number	Rubber Type	Amount of Carbon	Oil	tanδ	Hs
SG3907	SBR	Small	Not Included	0.18	54
SG3908		Medium		0.22	68
SG3909		Large		0.25	78
SG4105		Large	Included	0.27	70
SG4106		Medium		0.25	57
SG3902		Medium	Not Included	0.2	70
SG4101		Large	Included	0.24	70

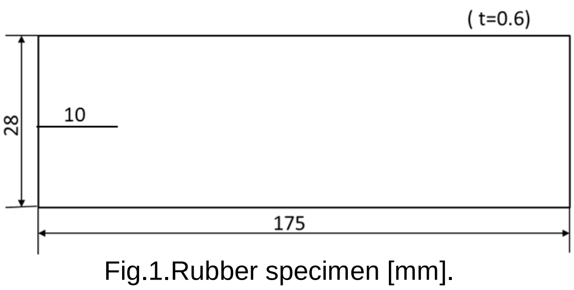


Fig.1.Rubber specimen [mm].

Test condition

The recording speed is 125 fps. The images are 1024 x 560 pixels (8 bits) for SG3902 and 1024 x 496 pixels (8 bits) for SG4101. Figures 2 and 3 show the analysis range. The analysis is performed by dividing the analysis into upper and lower parts separated by a yellow line. The subset size is 21 × 21 pixels.

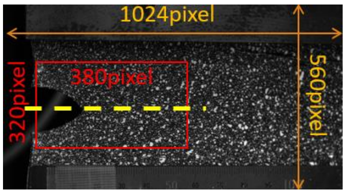


Fig. 2.Analysis range (SG3902).

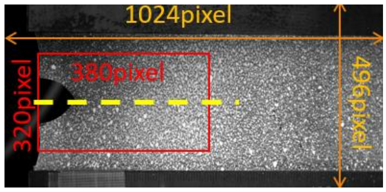
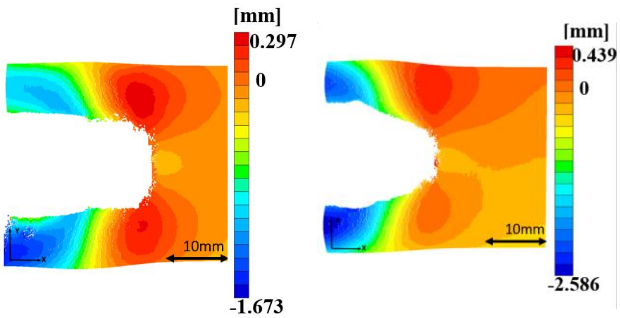


Fig. 3. Analysis range (SG4101).

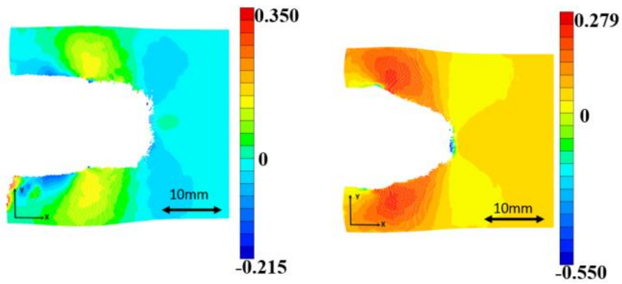
Results

Figure 4 shows the displacement distribution in the *x* directions when the crack growth length is 104 pixels (14.02 mm). The strain is obtained from the displacement, and the distribution is shown in Fig. 5. From the displacement distributin in the *x*, it is found that the displacement is large diagonally in front of the crack tip. Moreover, from the strain distribution, it is also found that strain concentration occurs near a crack.



(a) u_x (SG3902) (b) u_x (SG4101)

Fig. 4. Displacement distribution.



(c) ε_x (SG3902) (d) ε_x (SG4101)

Fig. 5. Strain distribution.

Figure 6 shows the relationship between crack speed and tearing energy. It is considered that the tearing energy at the time of speed jump is large due to the large energy loss. It is suggested that the input energy is dissipated and difficult to destroy due to the large energy loss. Fig. 7 shows the relationship between tearing energy and energy loss, the tearing energy increased as the energy loss increased regardless of the presence or absence of oil addition and the difference in the amount of carbon.

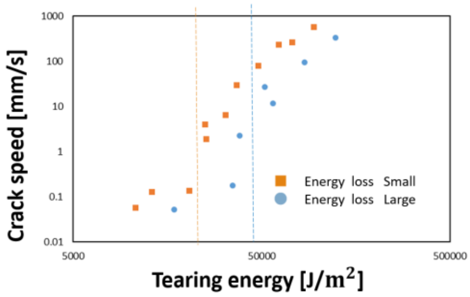


Fig. 6. Crack speed versus tearing energy.

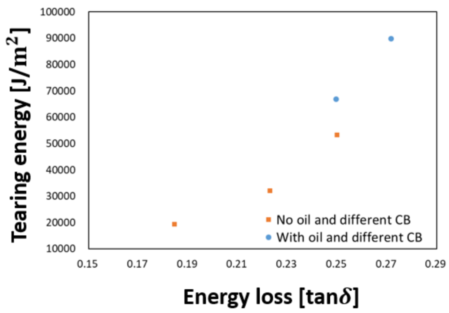


Fig. 7. Tearing energy versus energy loss.

Conclusion

A test is conducted on the rubber specimen containing the initial crack to observe the crack growth behaviour and the strain is calculated from the displacement obtained by the digital image correlation method. In addition, the tearing energy and the crack growth speed of each materials are calculated. The relationship between the tearing energy and the crack growth speed is graphed. From the graph, it is found that the difference in energy loss affects the magnitude of tearing energy. Furthermore, from the displacement and the strain distribution, the rubber material with a large energy loss uses the input energy not for crack growth but for crack opening to a large extent, so the crack growth is slower.

References

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[3] *Rublon, P. Huneau, B. Verron, E. Saintier, N. and Berghezan, D., Effect of strain-induced crystallization on fatigue crack growth resistance of natural rubber, Constitutive Models for Rubber [Ⅷ], (2013), pp. 349 - 354.*