Fracture Surface Analysis of Elastomers

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Abstract

Roughness profiles of fracture surfaces resulting from unstable crack propagation in a highly filled elastomer were analysed by means of height-height difference correlation functions. The fracture surface is anisotropic characterized by different roughness exponents along the crack front and along the crack propagation direction that are fairly equal to those found for fracture surfaces of other materials within the fracture process zone. Hence, a ductile fracture process can be conjectured within the corresponding length scales.

Introduction

The fracture of materials is a complex process where multiple length scales are involved. In material science, increased fracture toughness can be realised by modifying the structure of the material in such a way that as many as possible dissipative processes on various length scales are induced in the material resulting in a higher capability of the material to absorb energy during crack propagation. As can be seen mostly with the naked eye, structure modification of elastomers influences the resulting fracture surfaces as well.

Surfaces created by fracture are mostly irregular and rough. The morphology of fracture surfaces is signature of the complex fracture process at the scale of microstructure of the corresponding material. Even though roughness varies due to the different microstructure, roughness scaling properties are comparable for many materials. Fracture surfaces were found to be self-affine, first characterised by a universal roughness exponent $\zeta \approx 0.8$ [1]. But recent studies reveal that these fracture surfaces are anisotropic showing different roughness exponents along the crack front and along crack propagation direction. For a wide range of materials including glass, mortar, wood, quasicrystals and metallic alloys roughness exponents along the crack front and along crack propagation direction are $\zeta \approx 0.8$ and $\beta \approx 0.6$ [2,3,4]. However, it was found that fracture surface roughness exponents in glassy ceramics and sandstone are significantly lower, i.e. $\zeta \approx 0.4$ and $\beta \approx 0.5$ [5,6] challenging the universality of the higher roughness exponents.

Material and experimental setup

The results described in this paper were obtained from an emulsion styrene–butadiene rubber vulcanisate which was reinforced with 50 phr[1] carbon black N 330. The matrix was the non-crystallisable statistical styrene–butadiene copolymer SBR 1500 with a styrene content of 23.5 %.

[1] Parts per hundred rubber

Crosslinking was realised with a sulphur–accelerator system. The contents of the sulphur as well as the vulcanisation accelerator N-cyclohexyl-2-benzothiazole Sulfenamide (CBS) were 1.6 phr. Furthermore, 3 phr of the activator zinc oxide were added. The content of stearic acid as activator as well as processing additive was 1 phr. Lastly 1 phr of aging protective additive was used. The mixture was obtained by using a laboratory mixer and plates were vulcanised.

Fracture surfaces were obtained from a single edge notched tension specimen (SENT). Specimen dimensions were length L = 100 mm, width W = 25 mm and thickness B = 6 mm. Clamping distance was 40 mm. A notch of one forth of the specimen width was introduced by a razor blade. The fracture mechanical test was conducted in tension mode under quasi-static loading at 10 mm/min and room temperature. After short stable crack propagation, the sample was completely torn in an unstable manner.

Fracture surfaces as a result of unstable crack propagation were very smooth on the macroscale. The low macroscopic roughness occurring at higher filler contents at unstable crack propagation is a well-known phenomenon for carbon-black filled elastomers [7]. For further studies the surfaces were scanned in several 20×20 μm^2 areas with 1024x1024 data points by means of an AFM Q-Scope 250 (Quesant Instrument Corporation, USA) using intermitting mode at 2 Hz scan frequency. The measurement was done far from the notch where roughness statistics are stationary.

Results

The reference frame is chosen so, that e_x and e_z are respectively parallel to the direction of crack propagation and to the crack front. A typical AFM image of the fracture surface is shown in Fig. 1.

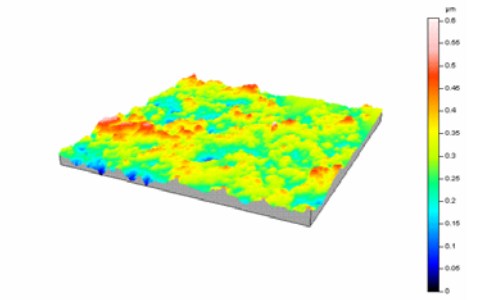

Figure 1: Typical AFM image of the analysed fracture surface

In order to analyse scaling properties, height-height correlation functions based on the second moment of the increments Δh on a scale Δx respectively Δz, i.e.

$$C(\Delta x) = \left\langle \left(h(x+\Delta x) - h(x)^2 \right) \right\rangle_x^{1/2} \tag{1}$$

for profiles along crack propagation direction and

$$C(\Delta z) = \left\langle \left(h(z+\Delta z) - h(z)^2 \right) \right\rangle_z^{1/2} \tag{2}$$

for profiles along the crack front, were calculated. The average was taken over the coordinate x respectively z.

The determination of roughness exponents was limited to the linear regime within the range between 80 nm and 400 nm. Typical height-height difference correlation functions of second order and the best linear fit are shown in Fig. 2.

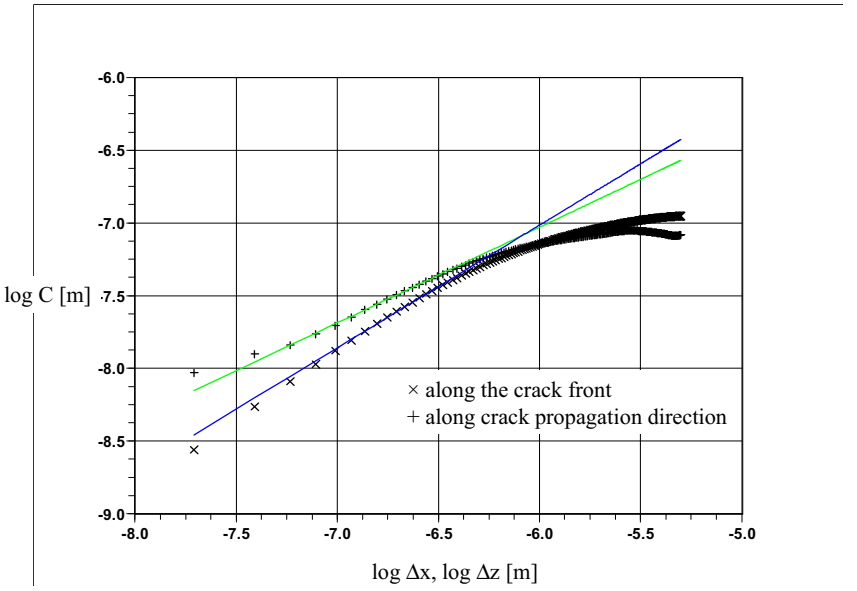

Figure 2: Typical height-height correlation functions

Analysis of all possible profiles of 7 different scans of the surface led to the roughness exponents in both directions and the corresponding standard deviation shown in Table 1.

Table 1: Determined roughness exponents for profiles of different AFM images

AFM-Image	β	ζ
1	0.65 ± 0.06	0.84 ± 0.04
2	0.71 ± 0.08	0.86 ± 0.04
3	0.71 ± 0.05	0.84 ± 0.03
4	0.67 ± 0.05	0.89 ± 0.02
5	0.66 ± 0.05	0.85 ± 0.03
6	0.76 ± 0.05	0.88 ± 0.03
7	0.73 ± 0.06	0.91 ± 0.03
Average	0.70 ± 0.06	0.87 ± 0.03

Discussion and conclusion

It was shown that fracture surfaces of the analysed elastomeric material are anisotropic characterised by the roughness exponents $\zeta = 0.87 \pm 0.03$ along the crack front and $\beta = 0.70 \pm 0.06$ along crack propagation direction within the range between 80 nm and 400 nm. These values are fairly equal to those found in other materials where exponents characterise the scaling behaviour within the fracture process zone [8]. Hence, a ductile fracture mechanism can be conjectured in the analysed material at unstable crack propagation.

Further results about fracture surface characterisation of elastomeric materials will be published in a forthcoming paper.

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References

[1] E. Bouchard, G. Lapasset, and J. Planés, Europhys. Lett. Vol. 13, 73-79 (1990).

[2] L. Ponson, D. Bonamy, and E. Bouchard, Phys. Rev. Lett., Vol. 96, 035506 (2006).

[3] L. Ponson, D. Bonamy, H. Auradou, G. Mourot, S. Morel, E. Bouchard, C. Guillot, and J. P. Hulin, Int. J. Fracture, Vol. 140, 27-36 (2006).

[4] L. Ponson, D. Bonamy, and L. Barbier, Phys. Rev. B, Vol. 74, 184205 (2006).

[5] L. Ponson, H. Auradou, P. Vié, and J. P. Hulin, Phys. Rev. Lett., Vol. 97, 125501 (2006).

[6] L. Ponson, H. Auradou, M. Pessel, V. Lazarus, and J. P. Hulin, Phys. Rev. E, Vol. 76, 036108 (2007).

[7] K. Tsunoda, J. J. C. Busfield, C. K. L. Davies, and A. G. Thomas, J. Mat. Sci., Vol. 35, 5187-5198 (2000).

[8] D. Bonamy, L. Ponson, S. Prades, E. Bouchard, and C. Guillot, Phys. Rev. Lett., Vol. 97, 135504 (2006).