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Fatigue crack growth behavior of NBR, HNBR, HNBR ZSC compounds

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Abstract

Due to the insufficiency of reliable data, fatigue life calculations taking the crack propagation phenomena into account, remain scarce. Therefore, this work focuses on the characterization of fatigue crack growth behavior for materials NBR, HNBR and HNBR ZSC in different thermal ageing states at different temperatures. The experimental data base was analyzed using Fracture Mechanics principles, namely crack growth rate in relation with the tearing energy. The tests of the notched pure-shear specimen were performed on a METRAVIB DMA+300 fatigue testing machine. It is found that the crack growth rate is approximately proportional to the tearing energy in the steady propagation range. Furthermore, the test temperature and thermal ageing were observed to be able to weaken the shearing strength.

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Keywords: crack growth behaviour, pure shear, notched sample, fatigue, rubber, nitrile.

Nomenclature

c	crack length	W	strain energy density
N	number of cycles	h	height of the pure shear sample
G	tearing energy		

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1. Introduction

Crack growth behavior is a significant characteristic for the durability assessment of rubber products in tire industries and anti-vibration components, specifically the rubber products cyclically loaded. This kind of cyclic load can lead to the weakening of the strength of rubber products by repeated deformations. Moreover, for the rubber products with cracks, these cracks will expand by the effect of cyclic load. Due to the cumulative feature of fatigue crack, the cyclic strain amplitudes are usually much lower than the fracture strain. A mass of crack experiments in fatigue have been done with tire materials, but much less with technical rubber.

The crack growth behavior can also be affected by thermal ageing and test temperature. The thermal ageing process affects the properties of material by heating rubber product during a certain period. The test temperature can affect the experimental process, by forcing the rubber into its rubbery zone instead of the glassy zone (high temperature) or the opposite (low temperature). In the condition of rubbery zone (high temperature) for example, the rubber exhibits a better elastic properties which can help to reduce the plastic deformation and the viscoelastic displacement. The aim of the fatigue crack growth experiments in this study is to investigate the effect of thermal ageing and of test temperature on crack growth behavior.

1.1. Relationship between crack growth rate and tearing energy

The most commonly used method for analyzing the crack growth behavior is to find the relationship between crack growth rates and tearing energy. Several years ago, LRCCP started to perform investigations on this topic by testing notched pure-shear specimen on a METRAVIB DMA+300 fatigue testing machine. When a specimen containing cracks is under cyclic load, the crack propagation will occur at the tip of the crack. By applying different cyclic strain amplitudes, the corresponding tearing energy will lead to a certain crack growth rate. The equation below is to describe the relationship between the crack growth rate and the tearing energy:

$$\frac{dc}{dN} = f(G) \qquad (1)$$

In this equation, c is the crack length, N is the number of cycles and G is the tearing energy at a specific deformation. It is possible to measure this crack growth rate of the specific tearing energy by the notched pure-shear test.

1.2. Machine

The crack growth experimental is performed with a dynamic testing machine METRAVIB DMA+300, which dedicated to the fatigue analysis of advanced materials and industrial components. It makes possible to characterize the mechanical properties of a wide range of materials and their dependence on various parameters: frequency, temperature, stress or strain amplitude, wave form etc. The introduction of crack and the observation of the crack growth can be achieved by cutting and magnifying optical systems. Furthermore, the tests could be performed on a wide range of temperature in the thermal chamber. The machine is shown in Fig. 1.

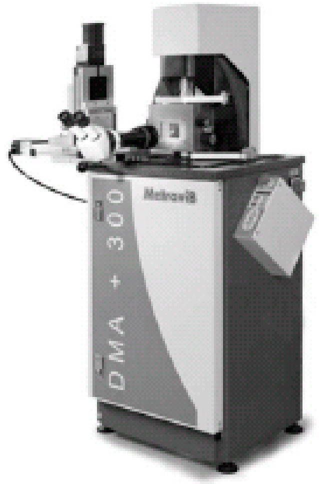


Fig. 1. METRAVIB DMA+300 machine.

1.3. Elastomer

The materials examined in this study were nitrile butadiene rubber (NBR), Hydrogenated Nitrile (HNBR) elastomers and HNBR ZSC elastomer. NBR is the elastomer most used in the automotive and aeronautical industry thanks to its excellent resistance to oils (depending on the ACN rate), its low price and its good mechanical properties. HNBR is also a good elastomer in contact with oils. It shows much higher resistance than NBR to heat, and to ozone. And HNBR ZSC provides unique polymer properties which offer improvements in tensile strength, abrasion resistance and dynamic properties. As the materials with a same base of NBR, their mechanic properties are similar, but there are still some difference in the strength.

2. Experiment

2.1. Pure shear test

The fatigue crack growth experiments used pure shear test specimen, as shown in Fig. 2. The test dimensions for the pure shear specimens were a length of 40mm, a height of 4mm, and a thickness of 0.8mm. Specific clamps have been developed to apply the dynamic loading to the sample.

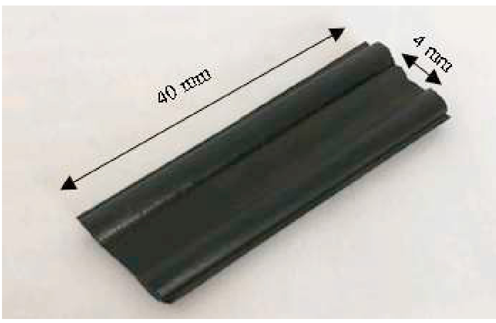


Fig. 2. Pure-shear test specimen.

The tearing energy G is determined from the strain energy per unit volume in that region of the test piece which is in a state of pure shear. The pure shear state is a specific biaxial loading (plane stress) which combines the stretches as follows:

$$\lambda_1 = \lambda \ , \ \lambda_2 = 1 \ , \ \lambda_3 = \frac{1}{\lambda} \qquad (2)$$

The loading axis being indexed 1, the length of the sample indexed 2 and the thickness indexed 3. The pure shear condition has an interesting advantage if the specimen is long enough, the tearing energy remains constant whatever the development of the crack propagation since the tearing energy G is so defined:

$$G = Wh$$

W being the elastic energy and h the height of the specimen.

2.2. Specimen preparation

Before the crack growth testing, a 3mm-long razor blade cut was introduced into the central axis of the two edges.

2.3. Materials

The specimens included NBR mixed with 70 parts of N550 carbon black per hundred parts of NBR, HNBR mixed with 70 parts of N550 per hundred parts of HNBR and HNBR ZSC mixed with 10 parts of N550, 50 parts of HNBR and 50 parts of ZSC. The 3 compounds are peroxide cured.

The specimens had been heated at 80°C with air atmosphere during 7 days and 21 days, which will be tested to investigate the effect of thermal ageing.

Table 1. shows the hardness (IRHD on samples) of every materials at different ageing states. At the same ageing state, NBR is the hardest in the three materials. It is assumed that NBR is more rigid than the others. For each material, increase the length of ageing treatment, the value of hardness slightly increase.

Table 1. The hardness of materials under different ageing states.

Hardness(IRHD on samples)	NBR	HNBR	HNBR ZSC
Original	85	79	79
7 days ageing	87	82	80
21 days ageing	88	83	81

2.4. Test procedure

In order to reduce the Mullins effect of rubber, a number of cycles slightly higher strain were applied to the specimen without notch. Then the relationship between deformation and tearing energy will be determined by testing with the specimen without notch. Finally, the specimen notched will be tested to investigate the relationship between the crack growth rate and the tearing energy. The experiments are performed at 23°C and 120°C to study the influence of test temperature on the crack growth behavior.

A travelling microscope will be used to observe the propagation of the crack and to determine the crack growth rate. The program of METRAVIB DMA+300 could calculate automatically the tearing energy by applied energy.

3. Results

The results of experiments are shown in the relationship between crack growth rate dc/dN and the tearing energy G on logarithmic scales.

3.1. Influence of test temperature

Fig. 3. shows the relationship between crack growth rate and tearing energy under the original state for NBR material, where one curve is for the tests performed at 23°C and the other for the tests performed at 120°C. Obviously, there is a huge difference between two curves. At G=100J/m^2, the crack growth rate at 120°C is 2500nm/cycle, and at 23°C that is only 10nm/min. The level of the crack growth rate at the given tearing energy increases significantly with the test temperature. Which correlates with the rubbery property of material. By increasing the temperature of rubber, it becomes softer and more flexible, and the ultimate properties strongly decrease. Besides, the test temperature of 120°C is excessively hot to the NBR compound.

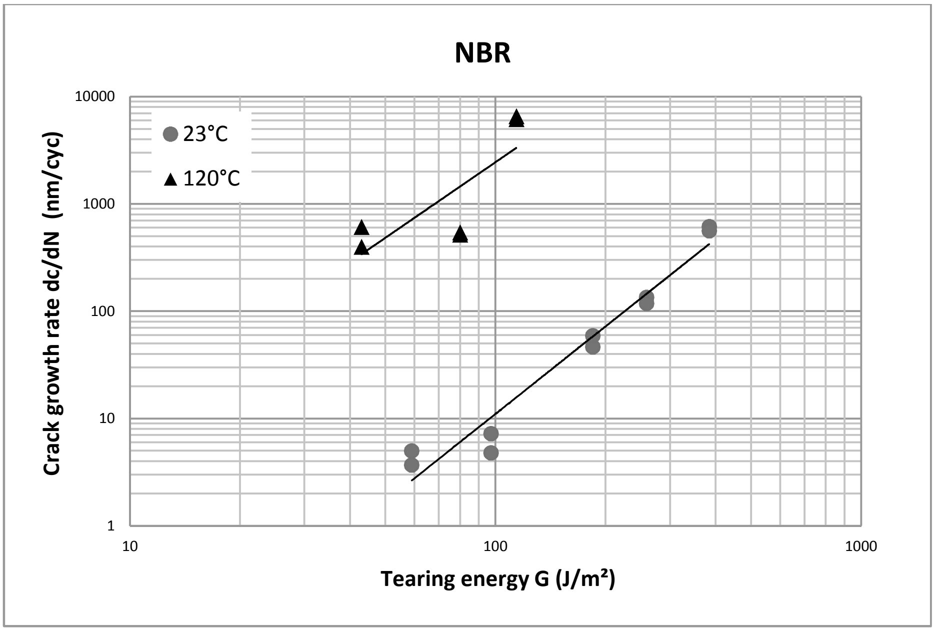


Fig. 3. crack growth behavior of NBR material under original state.

3.2. Influence of materials

Fig. 4. shows the relationship between crack growth rate and tearing energy under the original state for NBR, HNBR and HNBR ZSC materials. All the tests are performed at 120°C. At lower tearing energy like G=100J/m^2, the crack growth rate of NBR material is much faster than the others. The rates of HNBR and HNBR ZSC materials are located in the same order of magnitude. At higher tearing energy like G=400J/m^2, the crack growth rate of HNBR is five times faster than that of the HNBR ZSC.

Taking into consideration of hardness and properties of the three materials, among these materials, HNBR ZSC has the best strength, followed by the HNBR, and the NBR is lower than two others. So the experimental results give good agreement with theory.

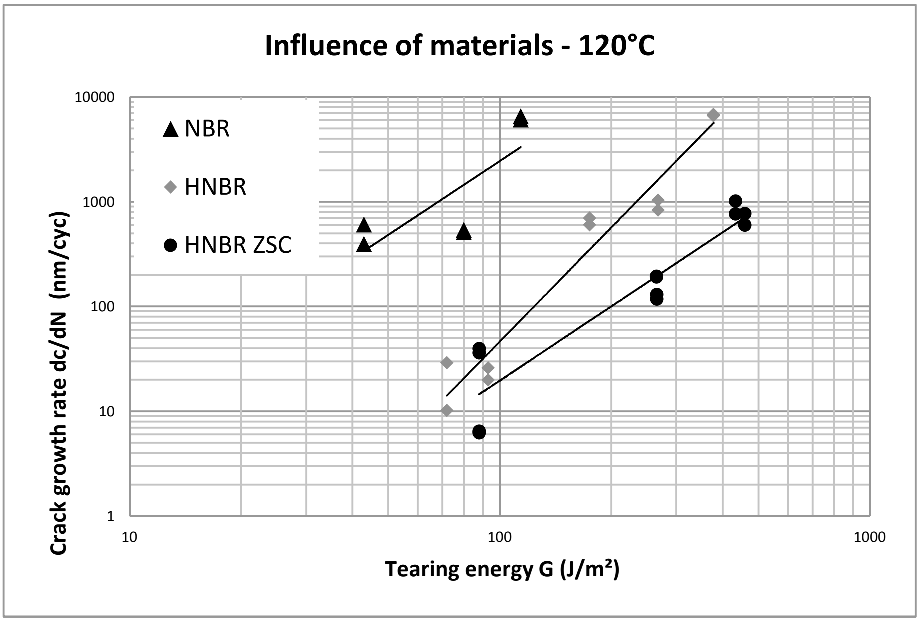


Fig. 4. Crack growth behavior at 120°C of NBR, HNBR, HNBR ZSC materials under original state.

Fig. 5. shows the relationship between crack growth rate and tearing energy under the 21 days ageing at 80°C state for NBR, HNBR and HNBR ZSC materials. All the tests are performed at 120°C. The experimental data indicates that these three materials have basically maintained the performance before ageing. There are only some slight changes of the crack growth rate under the same tearing energy.

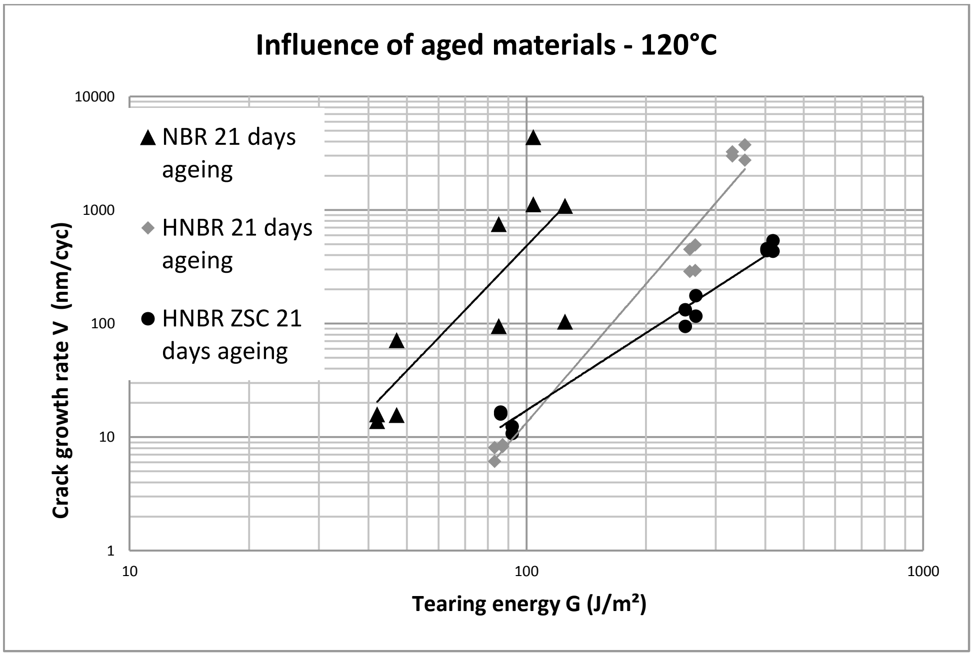
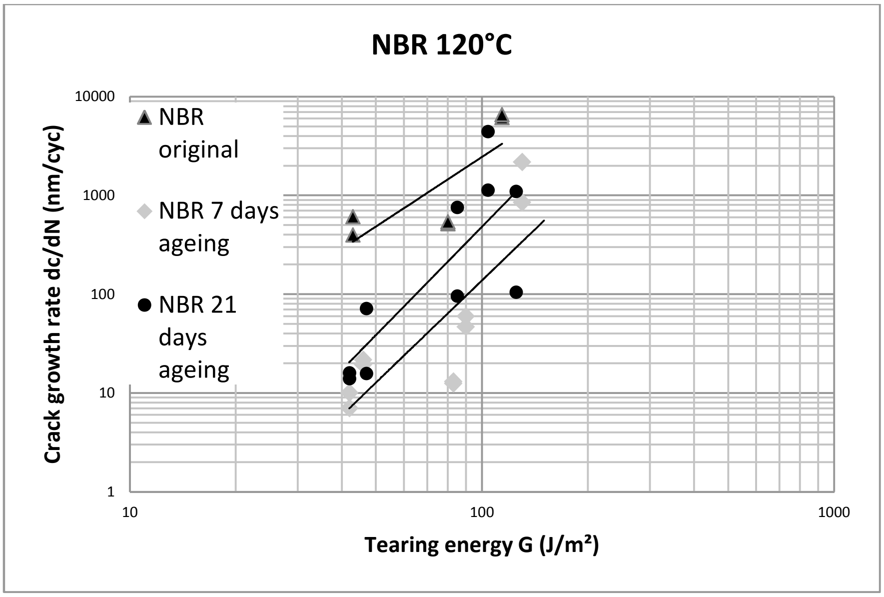
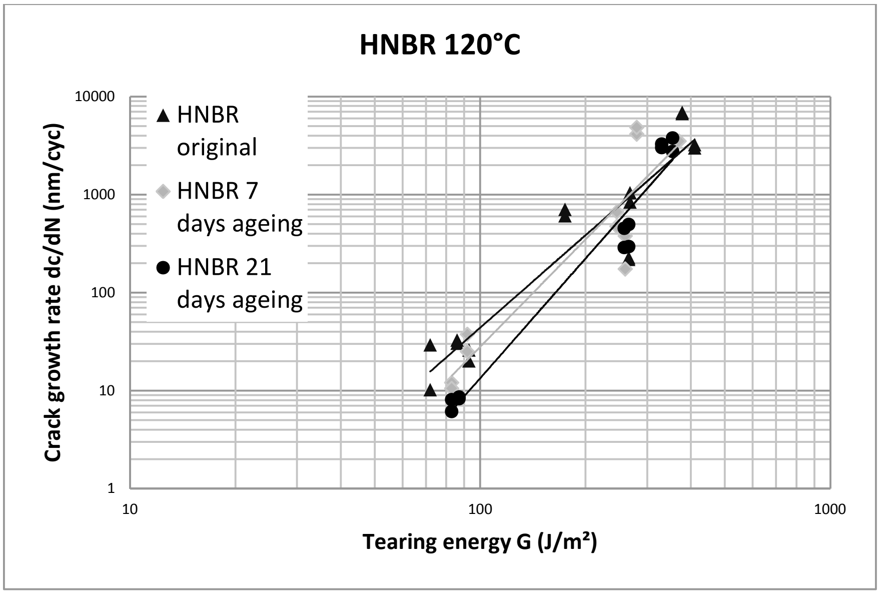


Fig. 5. Crack growth behavior at 120°C of NBR, HNBR, HNBR ZSC materials under 21 days ageing at 80°C state.

3.3. Influence of thermal ageing

Fig. 6. indicates respectively the relationship between crack growth rate and tearing energy of these three materials under different ageing states at the same test temperature of 120°C.





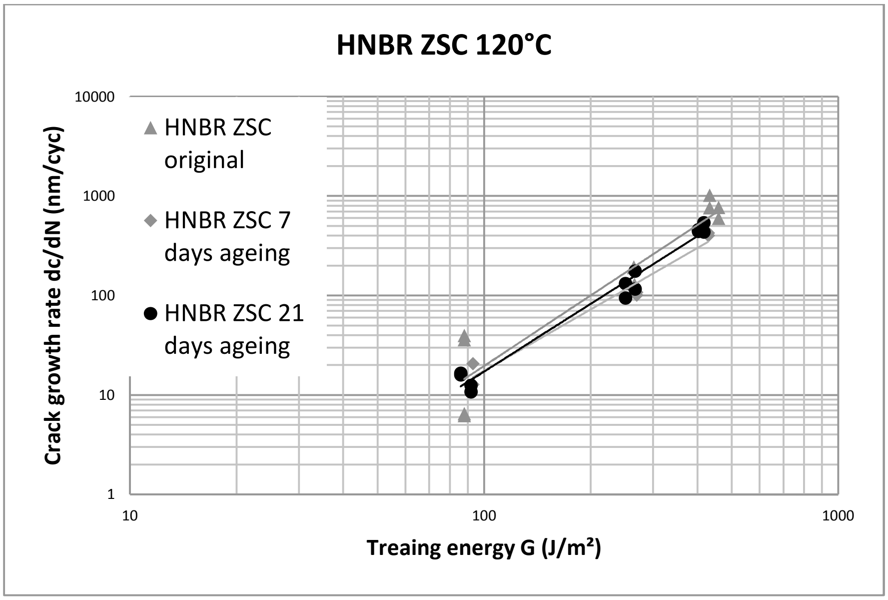


Fig. 6. Crack growth behavior at 120°C (a) NBR; (b) HNBR; (c) HNBR ZSC.

The three states act different crack growth behavior for NBR material, at a same tearing energy, the crack growth rates varies a lot along with the different ageing states. But for HNBR and HNBR ZSC materials, the crack growth behavior basically remains the same due to the resistance to heat of HNBR and HNBR ZSC is better than that of NBR. So the effect of thermal ageing is remarkable for NBR material.

4. Conclusion

For the formulations of this investigation, only with the NBR material, differences were found between different ageing states for the crack growth behavior. Furthermore independent of the test condition, under the same tearing energy, the crack growth rate of NBR is much greater than the two others. So the resistance to heat and shearing strength of NBR is less than the others. In consideration of the crack growth behavior of three different ageing states under the same testing condition, the anti-ageing properties of HNBR ZSC is slightly better than that of HNBR.

References

[1] K.Reincke, W. Grellmann, Halle/Saale, M.Luppel, Hannover, Investigation of fracture mechanical properties of filler-reinforced styrene-butadiene elastomers, 2009.
[2] A.N.Gent, P.B.Lindley, and A. G.Thomas, Cut growth and fatigue of Rubber, England, pp. 455-466, 1964.
[3] A.G. Thomas, rupture of rubber, England, pp. 467–480, 1958.
[4] I.C.Papadopoulos, A.G.Thomas, J.J.C.Busfield, rate transitions in the fatigue crack growth of elastomers, United Kingdom, 2007.