Experimental Studies of Thermal Aging Effects on the Tensile and Tearing Fracture Behavior of Carbon Black Filled Rubbers

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Abstract The effects of thermal aging on the tensile and tearing fracture behavior of carbon black filled rubbers with different filler loadings have been investigated in this paper. Thermal aging experiments were performed in a convection oven at 70°C and 120°C for various periods of aging time. Measurements of tensile strength, stretch to fracture and tearing strength were conducted with a 5943 Instron single column materials testing system as a function of aging time and aging temperature. It is found that the initial elastic modulus increases with increasing aging time, while the tensile strength decreases with the increase in aging time up to 100 hours and then increases when the material aged over 144 hours. The changes in tensile strength and stretch to fracture are found to be dependent on aging temperature, the higher the aging temperature, the more pronounced decrease in tensile strength and stretch to fracture. From the tearing fracture tests, the tearing strength generally is found to decrease with the increase in aging time.

Keywords Rubber, Thermal aging, Tensile strength, Stretch to fracture, Tearing energy

1. Introduction

Natural rubber is one of the most important elastomers, and its properties are usually reinforced by incorporation with carbon black (CB) of varying surface chemistry and aggregate size/aspect ratio to suit the application concerned [1]. CB filled rubbers are visco-hyperelastic materials, their mechanical properties are time- and temperature-dependent. Thermal aging causes both cross-linking and chain-scission. Cross-linking yields usually the increase in modulus and the decrease in extensibility of the material. Rubbers are susceptible to oxidative ageing due to their unsaturated carbon–carbon double bonds in the backbone. Elevated temperatures usually promote such an oxidative ageing [2]. The objective of this paper is to investigate the effect of thermal aging degradation upon the mechanical properties of filled rubbers with different CB loadings. The effects of aging are measured by the changes in tensile strength, stretch to fracture, initial elastic modulus and tear strength.

2. Experimental

2.1. Material and samples

The materials used for mechanical testing in this work are CB filled natural rubber vulcanizates. The formulations of the rubber compounds are listed in Table 1.Thin rectangular strips as shown in Fig.1, having the length of 100 mm and width of 10 mm, used for uniaxial tension tests are cut from a 2 mm thick vulcanized rubber sheet, which is provided by the Zhuzhou Times New Material Technology Co., Ltd. in China.

Table 1. Formulations of the rubber compounds (phr)

Compound	NR	CB (N330)	ZnO	Stearic acid	Antioxidant	Sulfur	Accelerator	Aromatic oil
A	100	11.2 *	5	3	1	2.5	0.7	3
B	100	37.6 *	5	3	1	2.5	0.7	3

* 11.2 phr CB = 5 vol% CB, 37.6 phr CB = 15 vol% CB

According to the ISO 34 standard method A, the samples used for tear fracture tests are processed into trouser test pieces. Each piece has a cut of depth 40mm, which is made with a razor blade, at the center of the width of the test piece in the direction indicated in Fig.2.

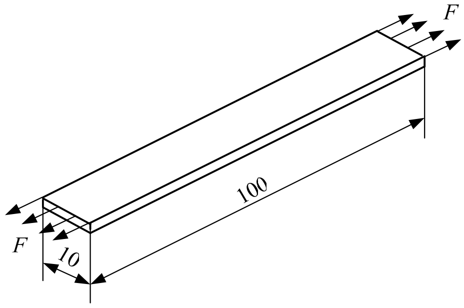

Fig.1 Test piece for uniaxial tension

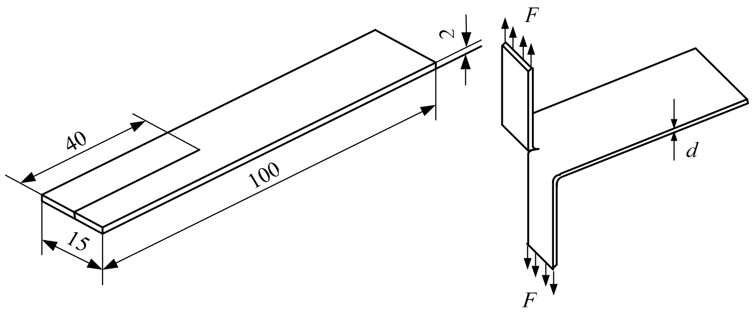

Fig.2 Trouser sample for tear fracture testing

2.2. Measurements

We examined the tensile and tear fracture properties of CB filled natural rubbers which have been subjected to isothermal aerobic aging. The thermal aging was conducted with a circulated air oven at temperatures of 70^{o}C and 120^{o}C for periods of time ranging from 10 hours to 144 hours. Uniaxial tension and tear fracture tests were conducted with a 5943 Instron single column materials testing system. The effects of aging were measured by the changes in tensile strength, stretch to fracture, initial elastic modulus and tear strength. The tensile strength is defined by the ratio of the peak force of the force-stretch curve to the reference cross section area. The Initial elastic modulus is the slop of the stress-stretch curve at very small stretches. The tear strength T_s is given by the formula

$$T_s = \frac{F}{d} \tag{1}$$

where F is the median force acting on the arm of the test piece, calculated in accordance with ISO 6133, d is the median thickness of the test piece.

3. Results

3.1. Tensile stress-strain properties

Uniaxial tension tests up to fracture under a constant rate of 100mm/min were conducted at 23^{o}C. Fig.3 shows the stress-stretch curves of rubbers with 5 vol% CB and 15 vol% CB, aged at 120^{o}C for various periods of time. It is obvious that the tensile strength, stretch to fracture and initial elastic modulus change with aging time. Figs. 4-6 show the variations of these tensile properties with aging time. It is found that the initial elastic modulus increases with increasing aging time, while the tensile strength decreases with the increase in aging time up to 100 hours and then increases when the material aged over 144 hours. Moreover, the stretch to fracture decreases with increasing aging time, this phenomenon was reported in the literature [3]. Compared to 5 vol% CB filled rubber, there are more pronounced changes in the tensile properties for 15 vol% CB filled rubber.
In vulcanizates the bond energy between the sulfur crosslink atoms and the polymer backbone greatly differ. There are three types of crosslinks in the vulcanizates: polysulfidic, disulfidic and monosulfidic [4]. The maximum service temperature of natural rubber is about 70^{o}C, i.e., the mechanical properties of natural rubber aged at 70^{o}C would not change significantly, however, the carbon black filled natural rubbers would experience severer thermal degradation at temperature above 70 ^{o}C [5]. As seen in Figs.7-9 the change in tensile properties are found to be dependent on aging temperature, the higher the aging temperature, the more pronounced decrease in tensile

strength and stretch to fracture, and the more pronounced increase in initial elastic modulus.

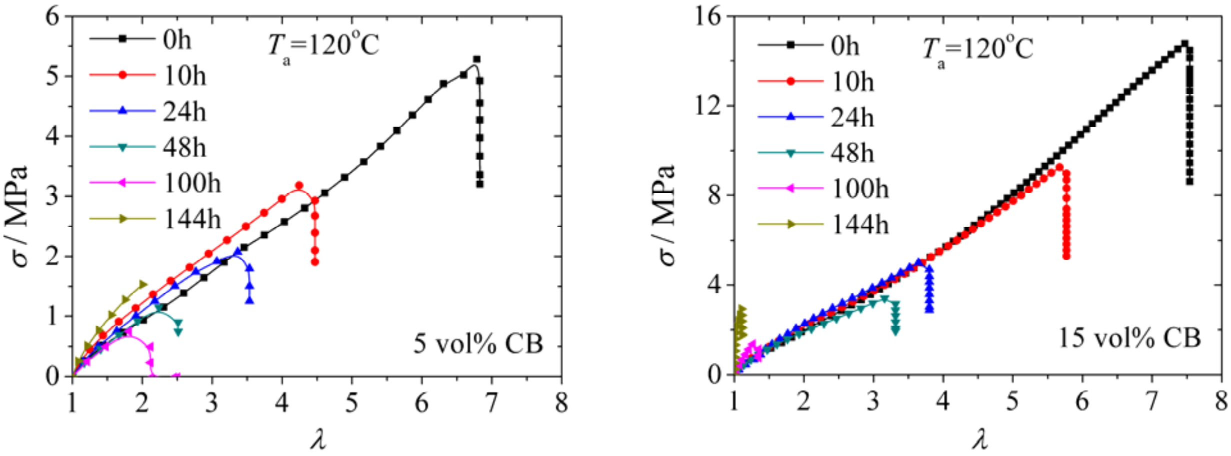

Fig.3 Tensile stress-stretch curves of filled rubber with 5 vol% and 15 vol% CB, aged at 120°C

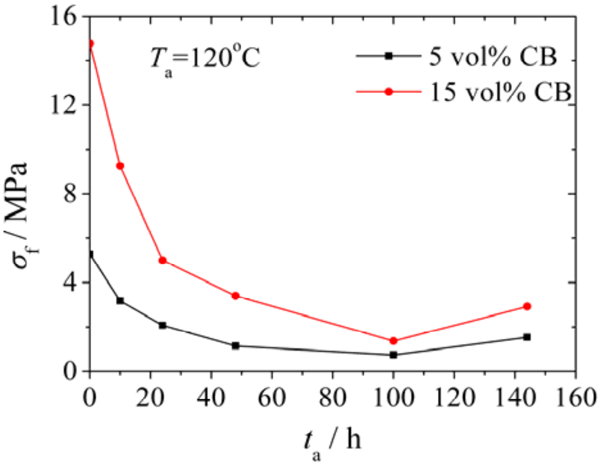

Fig.4 Variation of tensile strength with aging time for CB filled rubbers aged at 120°C

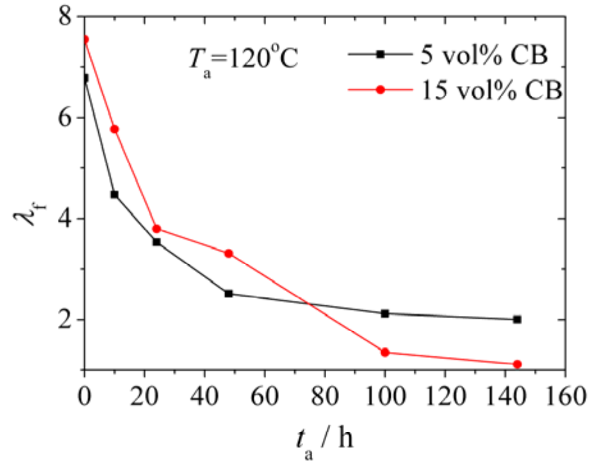

Fig.5 Variation of stretch to fracture with aging time for CB filled rubbers aged at 120°C

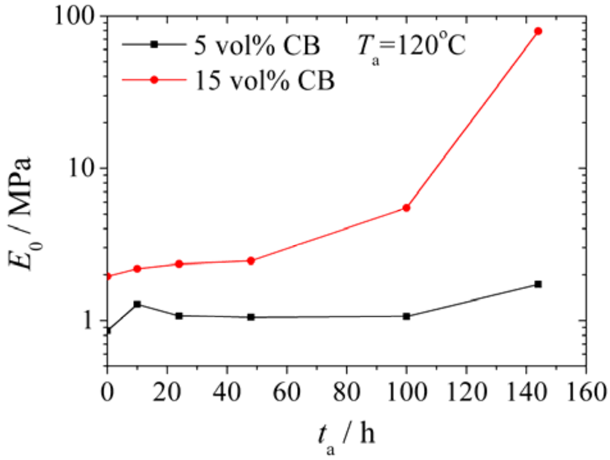

Fig.6 Variation of initial elastic modulus with aging time for CB filled rubbers aged at 120°C

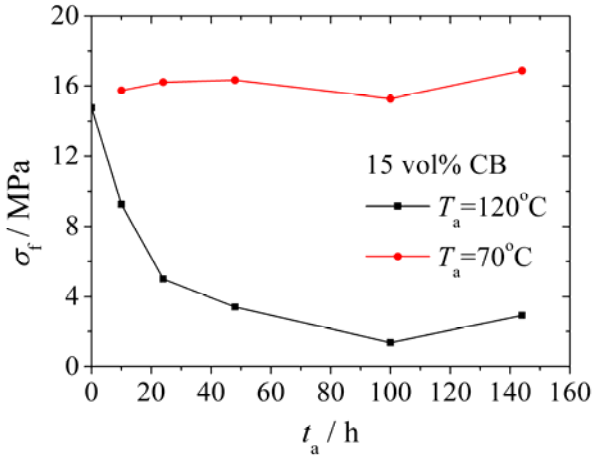

Fig.7 Variation of tensile strength with aging time for 15 vol% CB filled rubbers aged at 120°C and at 70°C

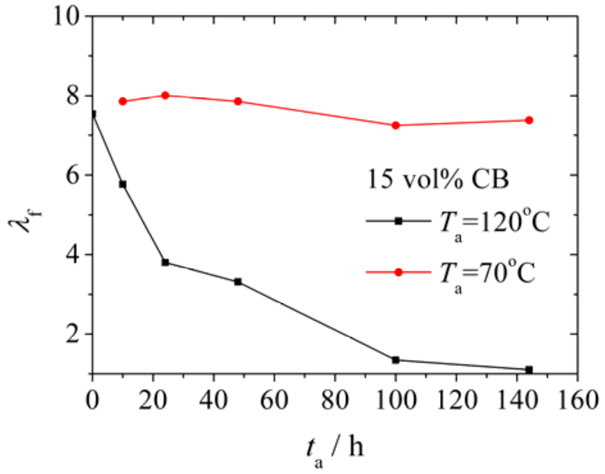

Fig.8 Variation of stretch to fracture with aging time for CB filled rubbers aged at 120°C and at 70°C

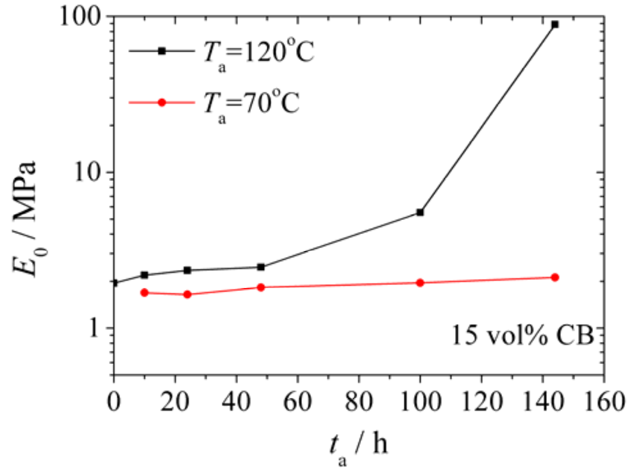

Fig.9 Variation of initial elastic modulus with aging time for CB filled rubbers aged at 120°C and at 70°C

3.2. Tear force-displacement curve and tear strength

Tear fracture tests under a constant rate of 100mm/min were conducted at 23°C. Fig.10 shows the tear force-displacement curves for 15 vol% CB filled rubbers aged for various periods of time at 120°C. The tear strength defined by Eq.(1) is plotted as a function of aging time as shown in Fig.11. It is seen that the tear strength decreases in the early aging period, and increases with aging time when the aging time extends to 48 hours. Such decrease-increase trend with respect to aging time is similar to the variation of the tensile strength with aging time.

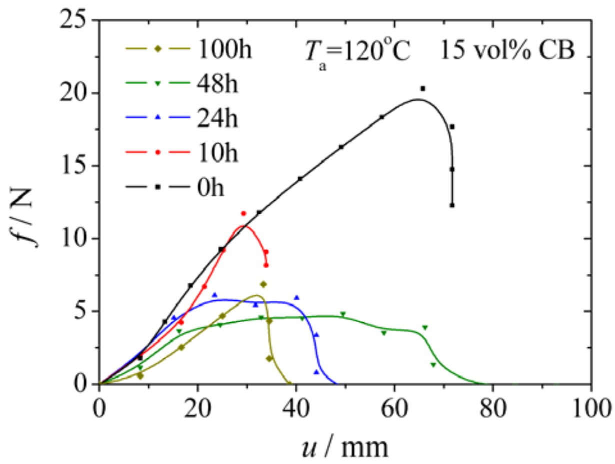

Fig.10 Tear force-displacement curve for 15 vol% CB filled rubber aged for various periods of time at 120°C

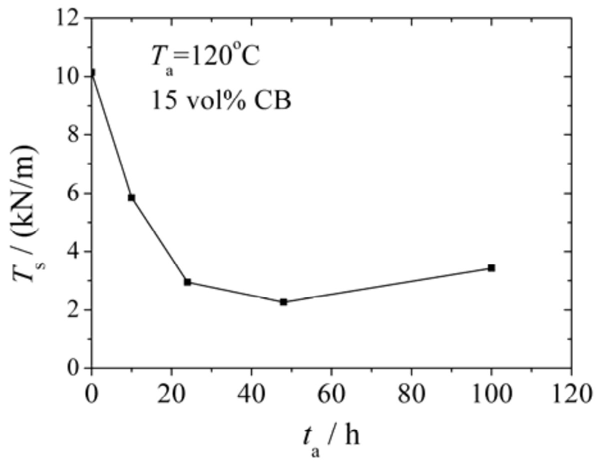

Fig.11 Variation of tear strength with aging time for 15 vol% CB filled rubber aged at 120°C

4 Conclusions

The effects of thermal aging on the tensile and tearing fracture behavior of carbon black filled rubbers with different filler loadings have been investigated in this work. It is found that the initial elastic modulus increases with increasing aging time, while the tensile strength and tear strength decrease firstly with the increase in aging time and then increase when the age proceeds. Moreover, the change in mechanical properties due to thermal aging is found to be dependent on aging temperature, the higher the aging temperature, the more pronounced deterioration in tensile strength and stretch to fracture.

Acknowledgements

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