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Rubber aging in tires. Part 1: Field results

John M. Baldwin*, David R. Bauer, Kevin R. Ellwood

Ford Motor Company, R and D Center, P.O. Box 2053, MD 3182, Dearborn 48121, MI, United States

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Abstract

Oxidative aging of skim and wedge rubber inside the tire results in a loss of peel strength and tensile properties of these rubber materials, which has been found to increase the likelihood of tread separations in certain tires. In order to develop an accelerated laboratory tire aging test, we have carried out extensive field and laboratory studies of rubber property change in tires. This paper describes the analysis of rubber oxidation in a specific set of tires collected from the field. In particular, we determine the rate of property loss under worst-case environmental conditions and analyze the implications of variability in aging results. The analysis is used in a companion paper to develop acceleration factors for different laboratory tests.

Keywords: Tires; Natural rubber; Oxidation; Field aging

1. Introduction

Certain tire disablements have been directly related to aging of specific rubber materials inside the tire. In particular, tread separations in a tire that was recalled have been linked to loss of mechanical properties of the skim and wedge rubber that bond the two steel belts together as shown in Fig. 1. Analysis by the National Highway Traffic Safety Administration (NHTSA) on tires collected from Phoenix, AZ determined that the aging mechanism of the skim and wedge rubber was aerobic oxidation [1]. That work, however, focused on only one tire brand/size from one manufacturer of which the tires had also been found to have a safety defect.

Changes in rubber properties of the tire steel belt package, after consumer use, are the focus of this paper. The analytical techniques used in this research include the measurement of peel force between the first and second steel belt, which is a measure of the tearing energy of skim rubber [2]. Tensile and elongation properties were obtained from samples of the wedge rubber located between the steel belts in the shoulder. The swelling ratio of the belt skim rubber was also measured allowing for determination of relative changes in crosslink density on aging. This research is part of a larger effort to develop an accelerated aging test for new tires. Accelerated aging results for the same tires studied here are described in a companion paper [3]. If a tire is to be aged in an accelerated fashion, then the field aging rate and mechanism must be known to validate the test. Based on the limited scope of the initial NHTSA study (and the suspect subject tire), it was decided to extend that work to a larger population of non-problematic tires of many different sizes (including LT metric tires), using similar analysis techniques. A full description of the Ford field retrieval design of experiment and initial results are contained in previous papers and are summarized below [4–6].

Fifteen tire-brand–vehicle combinations were collected from Phoenix, AZ; Los Angeles, CA; Detroit, MI; and Hartford, CT. Six different vehicle types and three different tire manufacturers were studied as detailed in Table 1. Vehicle–brand combinations are denoted by the vehicle type followed by the letter denoting the specific manufacturer, for example SUV/Minivan-A. The locations were chosen based on ambient

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* Corresponding author.
E-mail address: jbaldwin@exponent.com (J.M. Baldwin).

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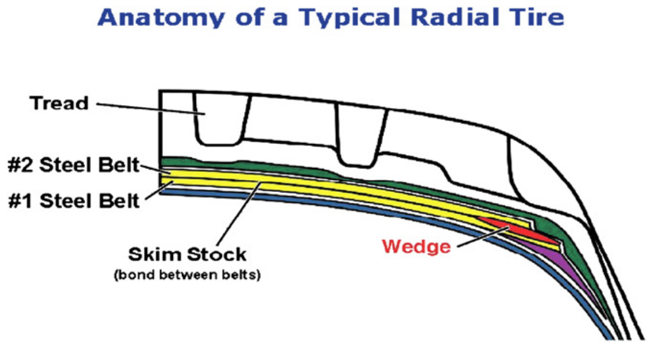

Fig. 1. Schematic of tire anatomy.

temperature and ozone level. Both on-road and full size spare tires were collected ranging in age from 2 weeks to 6 years. In total, over 1500 tires were analyzed in this study. A small number of tires from Miami, Fl and Denver, CO were collected to evaluate the effects for road roughness on aging. No significant effect was observed and these tires were not included in the current analysis.

Aging of the belt skim and wedge rubber was found to be quite general. Values for peel strength and elongation-to-break decreased with age while the crosslink density and modulus increased [5,7]. Detailed analysis of these changes following the method of Ahagon, confirmed that in all cases the changes were a result of oxidation [8]. The oxidation was relatively uniform across the belt. The rate of oxidation varied widely for different tire sizes and brands. Ambient temperature was found to be the only important external environmental factor in aging rate. Ozone did not affect the rate of aging. Tires in Phoenix aged ~2.5 times faster than tires in Detroit or Hartford and ~1.7 times faster than those in Los Angeles. These rates did not depend on the specific tire. Full size spare tires aged ~70% as fast as on-road tires, again, independent of external environment, tire brand or vehicle [7].

In addition to the Ford field retrieval study, NHTSA has carried out further studies of aging from tires retrieved from Phoenix [9]. Analysis in this paper will be limited to tires SUV/Minivan-A, -B, and -C; Large Car-C from the Ford study and a Small Car-B.F. Goodrich tire from the NHTSA study. Tire sizes and maximum inflation pressures for these tires are reported in Table 2. The analysis will focus on extracting accurate rate data from the field data. Of key importance is developing an understanding regarding the sources of variability in field aging. Field results will be compared to oven aging results in the companion paper [3].

Table 1
Vehicle-class, tire-brand combinations

	Large Car-F	Small Car-C	Truck U3855 B	Truck O3855 A	Perf Car-E	SUV/ Minivan-D
Brand A	x	x	N/A	x	x	x
Brand B	x	x	x	N/A	x	x
Brand C	x	x	x	x	N/A	x

Table 2
Tire sizes and inflation pressures

Vehicle type–brand	Tire size	Max. sidewall pressure (kPa)
SUV/Minivan-A	215/70R15	240
SUV/Minivan-B	235/75R16	300
SUV/Minivan-C	215/65R16	300
Large Car-C	225/60R16	240
Small Car-BFG	195/65R15	240

2. Rubber property measurements

Being cut from tires, the rubber samples in this work cannot be studied using standard test procedures. The specific techniques used to measure the rubber aging have been described in detail elsewhere and are summarized below [10]. The same techniques have been used to evaluate rubber aging in both the field study reported here and the laboratory oven study reported in the companion paper.

2.1. Peel strength

Samples were prepared by cutting 2.5″ (63.5 mm) wide radial sections, bead to bead. The sample was then sectioned into two 1.25″ (31.75 mm) radial strips, which were each cut circumferentially at the centerline of the tread resulting in four test specimens (2-SS and 2-OSS). Each sample was cut with a razor knife for a length of 1″ (25.4 mm) from the skim end of the test strip, midway between the belts, to facilitate gripping the ends in the T-2000 Stress/Strain Tester jaws. The sides of each specimen were scored midway between the belts, to a depth of 1/8″ (3.175 mm) radially from the end of the gripping surface to the end of belt #2 in the shoulder area, providing a 1″ wide peel section. The peel test was performed at 2″ per minute (50.8 mm/min) at 24 °C.

2.2. Tensile and elongation

Samples of the belt wedge rubber, located between belts 1 and 2, were removed from both shoulders (serial side and opposite serial side) and buffed to a uniform thickness of 0.5–1.0 mm. Care was taken so that no significant heat was introduced to the samples by the buffing. Specimens were die–cut using an ASTM D 638 Type V dumbbell die and tested per ASTM D 412. Results obtained included modulus values at the rate of 100%, ultimate elongation and tensile strength. Samples were tested at 20″ per minute (50.8 cm/min).

2.3. Crosslink density

Crosslink density measurements were determined on samples swollen to equilibrium in toluene after 24 h. Five specimens were tested for each sample. The volume fraction of polymer in the swollen gel was measured at equilibrium swelling and the crosslink density determined using the Flory–Rehner equation [11]. The polymer–solvent interaction parameter