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A methodology of life prediction of tyres

A look into the ARDL tyre aging and characterisation methodology which provides a novel technique for service life prediction of tyres

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This paper covers a methodology for service life prediction of tyres. The suggested testing programme should be conducted to characterise and understand the critical attributes of the inter-tread belt edge existing in new, aged and field tyres. This ARDL methodology to develop a reliable predictive testing protocol is useful for comparing tyre brands and the relative rates of degradation of their belt edge region (skim and wedge) compounds. The programme provides a quantitative measure of the relevant chemical, physical and dynamic properties leading to a rationale of the rubber at the belt edges deterioration mechanism.

The United States Congress passed the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act in November 2000. Included in the Act were specific directions to the National Highway Traffic and Safety Administration (NHTSA) to upgrade the tyre safety standards within two years.

U.S. Congress stated that there is a need for aging test(s) on tyres since most tyre failures occur at a point in the service life of a tyre greater than the 1,700 miles experienced by a tyre in the current FMVSS No. 109 endurance test. There are no current requirements for accelerated tyre testing in FMVSS Nos. 109 and 119, and no industry-wide recommended

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increased about 5 MPa and then 25 MPa after 47 days. This particular data was taken on a portion of the tread lug near a groove. For this reason, the tread modulus was high about 9 mm below the tread surface.

The diffusion-limited effects are captured in the model predictions. The oxygen consumption is very high in the plycoat and tread, limiting oxygen diffusion into the internal components.

Summary

The degradation mechanism in a passenger tyre was examined. During the life of a passenger or light truck tyre in the field, the primary degradation mechanism was oxidation. Except for the innerliner, the tyre components were oxidizing at about 1.5x10-12 moles O2/g-s.

Furthermore, in the strain region at the belt edge another degradation mechanism was observed. The degradation mechanism in the gumstrip was mechanical softening in addition to oxidation. The aging of a field tyre was compared to an oven-aged tyre.

During oven-aging the primary degradation mechanism was oxidation; however, the oxidation rate in the 'exterior' components was significantly greater than the oxidation rate in the internal components.

Oven aging oxidizes the belt package in a short time (weeks); however, the exterior components oxidized relatively faster than the internal components.

The plycoat and tread were oxidizing at about 3.0x10-11 moles O2/g-s and the gumstrip was oxidizing at about 1.3x10-11 moles O2/g-s.

Also, the influence of mechanical softening was determined through the use of modulus profiling, which can measure low-strain modulus in small regions of the tyre. Oven aging appeared to do some mechanical softening in the belt package, but less than the field tyre.

Conclusions

1. The influence of oxidation and mechanical softening was determined through the use of modulus profiling, which can measure low-strain modulus in small regions of the tyre.

2. The degradation mechanism in the belt edge gumstrip during normal service was mechanical softening in addition to oxidation.

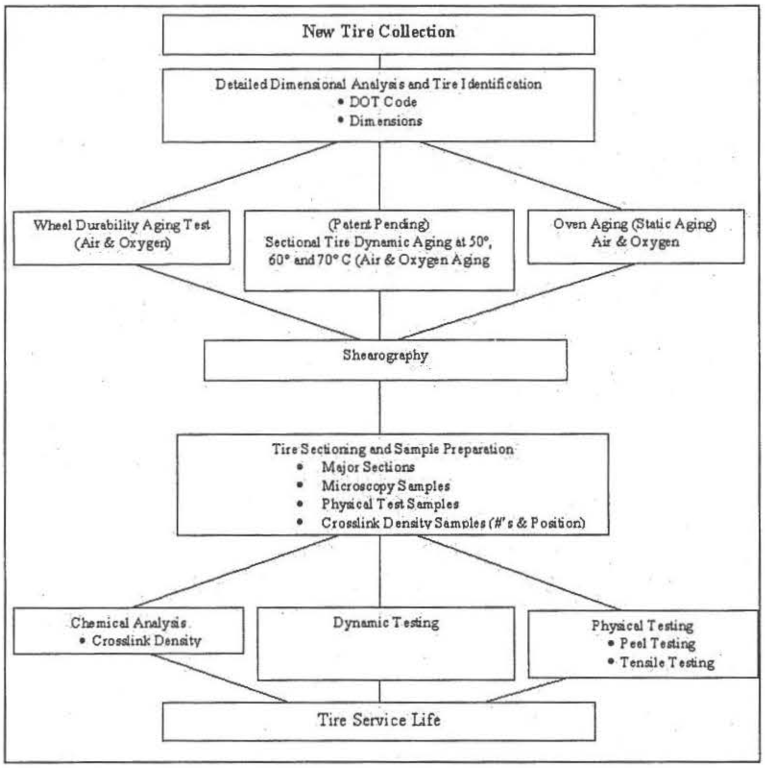
3. Oven aging a tyre oxidizes the belt package in a short time (weeks); however, the exterior components oxidized relatively faster than the internal components.

4. Oven-aging alone does not sufficiently capture the mechanical fatigue experienced by a field tyre from interlaminar shear strain. Accelerated tyre age testing should incorporate both chemical aging and mechanical fatigue. ☐

practice for accelerated tyre aging test. NHTSA decided to develop an aging test(s) and plans to include it in FMVSS 139 within the next 2 years.

Current tyre failure hypothesis

A principal cause of premature failure of steel-belted radial tyres is attributable to the combined effects of induced stress-strain and the aging of the rubber components in the belt region (skim and wedge) of the tyre. These effects can be measured; moreover, once obtained and understood, changes in these properties can be used to assess and predict tyre service life. Predictive aging of tyres requires input from laboratory aging data. The goal of lab aging is to accelerate age of a new tyre to the equivalent condition of a field-aged tyre.



There are two main objectives of tyre aging. One is to compare a lab aged tyre to field-real-life aged tyre. The other objective is to compare the lab aged tyre to a new tyre and compare its degradation rates in comparison to the real world degradation rate properties. There are two main classes of lab aging a tyre: thermal lab aging and thermo mechanical lab aging. Thermal aging can be done on a tyre by statically oven aging a tyre under varying mixtures of cavity gases. Thermo mechanical aging relies on oven aging a whole tyre or a section of the tyre under constant mechanical stress to simulate real world field variables more effectively

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Tyre aging mechanism

The aging mechanism of internal tyre compounds (such as the belt coat) is different for accelerated wheel testing and long-term road use. The argument is that during wheel testing relatively high sustained temperatures reduce the availability of oxygen to internal tyre rubber components. Oxygen cannot diffuse fast enough to the site of reaction, and aging is mostly anaerobic. During road use, temperatures are lower and driving is not sustained but interrupted by frequent stops. Under these conditions aging reactions are much slower and there is greater availability of oxygen at the reaction site. Here aging is mostly aerobic.

The differences in aging mechanism (anaerobic or aerobic) that are described above are considered important because they affect rubber properties differently. It has been shown that differences in inflation medium have a significant impact on tyre time to failure on wheel testing. An oxygen enriched inflation gas medium wheel test increases and more closely simulates the aging mechanism that is seen in service.

Oxidation encompasses a multitude of complex reactions, with the dominant reaction being crosslink formation. Oxidative crosslink formation in rubber results in increased modulus. The rate of oxidation, crosslink formation and modulus increase shows an exponential dependence on temperature, in line with the Arrhenius relationship.

Conversely, during anaerobic or thermal aging, sulfur cured rubber compounds which are based on natural rubber, such as the belt skim, base or ply skim compounds exhibit crosslink scission. Anaerobic crosslink scission in sulfur cured natural rubber compounds results in reduced modulus (or reversion). The rate of reversion and modulus decrease is affected by temperature in line with the Arrhenius relationship.

The diffusion-limited oxidation mechanism would expect to result in an oxidation gradient. It has been pointed out that this diffusion gradient should be affected by external factors such as oxygen availability (oxygen concentration in the tyre inflation medium) and compound type (oxygen consum-

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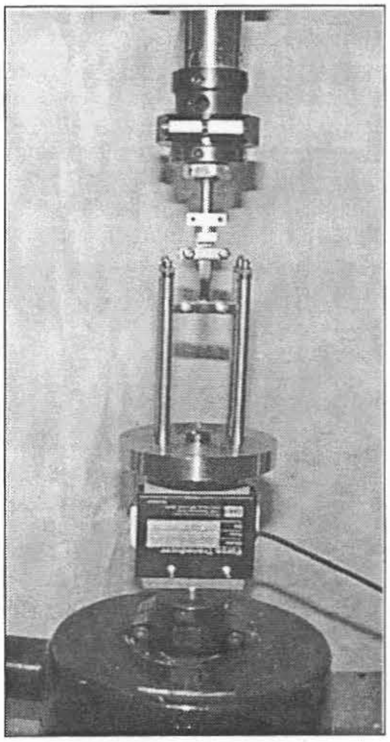

ption rate constant).

Tyre aging mechanisms and models

·Tyre aging mechanisms

o Mechanical Softening

o Thermal Reversion

o Oxidation

· Oxidation

o Diffusion-limited oxidation model

§ Oxygen diffusion

§ Oxidation rate

§ Comparison of model predictions to experimental results

·Aging models (degradation kinetics)

o Crack growth

o Residual strength approach

o Cumulative damage approach

o Develop diffusion limited oxidation model

§ Provide input data

§ Provide model

§ Validate model

o Develop aging model

§ Crack growth rate

§ Material property decay

§ Kinetics

o Combine aging model with tyre models

§ Cracking energy density

§ Tear energy

§ FEA

Testing

1. Unaged stress/strain.

2. Dynamic testing, MTS 831 machine at different frequencies, strain amplitudes, and temperatures.

3. Analytical technique to determine the sulfur crosslink structure at the wedge region. The types and amount of monosulfidic and polysulfidic crosslinks.

4. Fatigue crack growth study.

5. FEA of the "inter-ply" region using the material properties from the above tests and geometrical variation of the "Inter-ply".

Figure 1: ARDL Tyre Aging/ Characterization Protocol

(New tyre laboratory aging and field tyre characterization)

Test significance:

Belt ply separation may be due to high service strain, due to anisotropy of plies and the dynamic moduli mismatch of cords and rubber, and bulk stresses at the belt edge.

1. Tensile testing: Unaged stress/strain.

2. Dynamic testing: Determine the change in dynamic properties (E*, E', E" and Tan delta) at large strains at elevated temperatures.

3. Modulus profile: A technique to determine the modulus of the various tyre layers/components.

4. Fatigue crack growth testing: A technique to determine the crack growth rate (Mini Demattia).

5. Finite element analysis: FEA of the "inter-ply" region will be conducted using the material properties from the above tests as well as geometrical variations of the "inter-ply" components. FEA can be used to predict the fracture strength and structural integrity of the wedge region as a function of "inter-ply" thickness and various moduli under a variety of conditions (static, dynamic, impact and aging).

6. Crosslinking and types of crosslinks: The degree of crosslinking or crosslink density in a three-dimensional rubber vulcanizate has been long known to affect certain fundamental properties of thermoset materials. The ease of rationalizing root failure causation and predicting tyre service varies with the type of polymer present, but reliable estimates can be made based on the degree, extent, or amount of crosslinking that is present in the network structure. The higher crosslinking provides an increase in hardness, resilience, abrasion, and fatigue cracking typically increases; whereas, elongation, heat build-up, swelling, creep, stress- relaxation, and low temperature crystallization rates usually decreases. Predictions become more refined and ▶

Predictions become more refined and property-specific as the type of chemical crosslinks within the network structure are identified

property-specific as the type of chemical crosslinks within the network structure are identified.

These analytical methods for determining the type of sulfur crosslinks, or rather the average number of sulfur atoms that make up one chemical crosslink, involve crosslink cleavage using chemical probes comprised of thio-amine reagents.

There is little doubt that the presence or predominance of a given crosslink type or types influence certain specific mechanical properties that affect service life. The increasing demand for reliable predictions of elastomer performance in specific environments or unique applications mandates selection of specific vulcanization systems in optimizing properties or a specific property in an elastomeric material in order to achieve enhanced service life. Premature failures become more understood by relating the accelerator(s)/sulfur system used to manufacture the product to the types and percentages of types of crosslinks found in the failed product.

The service life prediction effort conducted on elastomeric materials provides a good materials database for computer-aided design engineers who in turn can use the information to effectively model part durability

As increased di- and poly-sulphidic crosslinks occur, an increase in compliance, creep, stress relaxation, set, and fatigue life is observed. Increased mono-sulphidic type chemical crosslinks reflect increased resilience, thermal aging, heat resistance, heat buildup in dynamic applications, as well as increased solvent resistant properties.

Failures that occur in dynamic applications, thermal environments, and excessive stress-bearing applications are readily explained when the types of chemical crosslinks and the changes that have occurred in the types of chemical crosslinks during the product life cycle are elucidated.

ARDL's analytical testing includes classical quantitative measurements as well as the latest advanced state-of-the-art research and testing methods.

Test parameters

Determine the mechanism of aging in rubber compound components during laboratory accelerated aging. (Sectional fatigue testing, wheel testing and oven aging.)

Determine the effect of different belt skim compounds (differing in inherent oxidation) on aging mechanism of the belt skim in the belt edge area.

1)Tabulate Data for the following parameters:

Modulus of rubber samples in the shoulder region of new tyres accelerated aged tyres.

Crosslink density and crosslink distribution of rubber samples taken out of the tyre wedge region of new tyre, wheel tested, sectional test tyres, oven aged tyres and field tyres. Samples to be taken out of the tread, the base, the overwrap coat, the belt coat, the ply coat and the innerliner.

Mini Demattia flex type cut growth values of rubber samples taken out of the belt compound at the belt edge of new tyres, wheel tested, sectional test tyres, oven aged tyres and field tyres.

Tensile properties of rubber samples taken out of the belt compound at the belt edge of new tyres, wheel tested, sectional test tyres, oven aged tyres and field tyres.

Interfacial tear peel testing of the inter belt, rubber coat compound of new tyres, wheel tested, sectional test tyres, oven aged tyres and field tyres.

MTS dynamic properties of rubber samples taken out of the shoulder region of new tyres, wheel tested, sectional test tyres, oven aged tyres and field tyres

A novel technique

This ARDL tyre aging and characterization methodology provides a new technique for service life prediction of tyres. The dynamic modulus indicates how well the tyre wedge compound will work during service impact and flexing.

The modulus is dependent on the temperature, strain and strain rate. This large increase in modulus of one layer in the "composite tyre belt" structure can lead to serious modulus mismatch in the "inter-belt" region.

The above approaches can be applied to determine life of elastomers inter-ply belt region (skim and wedge). However, it is important to define failure mode and failure mechanism. It is also important to establish verification and correlation between field and lab samples using physical and chemical techniques.

The primary rate determining mechanism of component failure can be predicted using the Arrhenius methodology. The Arrhenius method provides a quantitative determination of the service life of elastomer components in a particular application. Further research studies are required for each new application.

The service life prediction effort conducted on elastomeric materials provides a good materials database for computer-aided design engineers who in turn can use the information to effectively model part durability, thus reducing the need for complex and costly prototype testing. □