A Novel Approach to Predicting the Lifetime of Elastomers Undergoing Stress Relaxation

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Abstract

This work opens with a broad overview of several factors influencing the behaviour of elastomeric materials under constant deformation. Following this, an evaluation of the common difficulties surrounding industry-standard lifetime prediction methods is presented. Subsequently, a novel method for the lifetime prediction of stress relaxation in elastomeric materials under constant deformation is introduced.

Experimental testing to determine the influence of filler type and content was conducted on several natural rubber materials. The effect of altering the vulcanising agent, crosslink density and mixing time was also examined. Chemiluminescence was used to determine the influence that oxidation has on the overall life of elastomers.

A critical assessment of current industry-standard lifetime estimation methods are presented through practical examples. This work evaluates some of the common problems surrounding these lifetime prediction methods and discusses their limitations.

Comprehensive investigations were initiated to develop the time and temperature dependent fitting of relaxation data using spectral analysis. A novel concept is introduced to accurately predict the long-term behaviour of elastomers under constant deformation. The concept of analysing relaxation spectra and Arrhenius extrapolation offers a promising route to more accurate lifetime predictions.

Keywords: stress relaxation, elastomer, lifetime prediction, spectral analysis

I certify that this thesis which I now submit for examination for the award of PhD, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Signature_____________________________Date______________

Candidate

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Glossary

ACM	Acrylic Rubber
ASTM	American Standard for Testing of Materials
ATR	Attenuated Total Reflection
CB	Carbon Black
CBS	N-cyclohexyl-2-benzothiazole sulfenamide (accelerator)
CL	Chemiluminescence (emission of light from a chemical reaction)
CV	Conventional Vulcanisation
DIN	Deutsches Institut für Normung
DMA	Dynamic Mechanical Analysis
EPDM	Ethylene Propylene Diene Polymer
EV	Efficient Vulcanisation
FEA	Finite Element Analysis
IPPD	N-isopropyl-N'-phenyl-paraphenylenediamine
ISO	International Organisation of Standardisation
NBR	Acrylonitrile Butadiene Rubber
NLREG	Non-linear Regularisation
NR	Natural Rubber
OIT	Oxidation Induction Time
PMT	Photo Multiplier Tube
RSA	Rheometrics Solids Analyser
SBR	Styrene Butadiene Rubber
SEV	Semi-efficient Vulcanisation
SLS	Standard Linear Solid
TBBS	N-tertbuty1-2-benzothiazole Sulfenamide
TBzTD	Tetrabenzylthiuram disulfide
TMQ	1,2-dihydro-2,2,4-trimethylquinoline
TMTD	Tetramethylthiuram disulfide
TTSP	Time-temperature superposition principle
UV	Ultraviolet
WLF	Williams-Landel-Ferry
XLD	Crosslink Density

Nomenclature

T_g	Glass transition temperature (°C)
phr	Parts per hundred resin
S_1	Monosulphidic crosslinks
S_2	Disulphidic crosslinks
S_x	Polysulphidic crosslinks
E’	Storage modulus (Pa)
E’’	Loss modulus (Pa)
E*	Complex modulus (Pa)
G’	Dynamic storage modulus (Pa)
G’’	Dynamic loss modulus (Pa)
Tan δ	Loss factor
ε	Strain
σ	Stress (Pa)
τ	Relaxation time (s)
η	Viscosity (Pa.s)
F	Force (N)
$F_{(1)}$	Force after 1 minute (N)
$F_{(30)}$	Force after 30 minute (N)
$F_{(t)}$	Force after time *t* (N)
$E_R^{(10)}$	Stress relaxation modulus (at 10 seconds) (Pa)
R	Gas constant = 8.314 (J/Kmol)
E_a	Activation energy (KJ/mol)
t_{90}	90% of time to complete curing (S)

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