

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

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September 2009

## **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

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Candidate

## **Acknowledgements**

First and foremost, I would like to express my sincere gratitude to Dr. Thomas Alshuth whose extensive knowledge and experience has been immensely important to me and this work. Your understanding, encouragement and guidance have provided the backbone of this thesis.

I owe my deepest gratitude to Dr. Steve Jerrams. Thank you for your persistent confidence, your detailed and constructive comments and your invaluable support.

The following research would not have been possible without the support of the School of Manufacturing and Design Engineering and the Directorate of Research and Enterprise. Thank you for making this work a reality.

I would like to thank the entire CER team, in particular Niall Murphy who introduced me to the field of material science.

I wish to extend my warmest thanks to Prof. Robert Schuster for providing me with the opportunity to carry out my research at the Deutsches Institut für Kautschuktechnologie (DIK). Thank you for the many travel opportunities from France to Brazil to our weekend ski trips in the Harz.

During this work I collaborated with many colleagues for whom I hold the highest regard. I wish to extend my gratitude to all those who assisted in the successful realisation of this work. In particular, I would like to thank Dr. Eva Peregi for her network structure analysis and Markus Santoso for the Chemiluminescence investigations.

I am grateful to the DIK laboratory technicians, in particular Peter for his generosity and professional assistance. You continue to make DIK a fun and memorable experience for all students.

My special thanks go to my many colleagues and friends. We will always remember our city-centre office, McGowans Irish Pub, where stress relaxation increased exponentially with black filler. A special mention goes to my good friends Cristian, my IT guru, and Stefan for those in-depth Friday morning discussions.

I am indebted to John McNamara, your friendship and support throughout my time in Germany will never be forgotten.

To Izabel, thank you for your support and constant encouragement.

Finally, I remain forever indebted to my parents and family for all the support and encouragement they have given me throughout my studies. I could not have done this without you. R.R. you're a star!

## 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-tertbutyl-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 ( $^{\circ}\text{C}$ )
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 $\delta$	Loss factor
$\varepsilon$	Strain
$\sigma$	Stress (Pa)
$\tau$	Relaxation time (s)
$\eta$	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)

## Table of Contents

<b>Abstract</b> .....	<b>ii</b>
<b>Acknowledgements</b> .....	<b>iv</b>
<b>Glossary</b> .....	<b>vi</b>
<b>Nomenclature</b> .....	<b>vii</b>
<b>List of Figures</b> .....	<b>x</b>
<b>List of Tables</b> .....	<b>xii</b>
<b>Chapter 1 Introduction</b> .....	<b>13</b>
1.1 Motivation and Industrial Imperative.....	13
1.2 Aims and Objectives .....	14
1.3 An Overview of the Research .....	15
<b>Chapter 2 Stress Relaxation - A Literature Review</b> .....	<b>18</b>
2.1 General Properties of Elastomers .....	18
2.1.1 Long-term Properties of Elastomers .....	19
2.1.2 Hyperelasticity .....	20
2.1.3 Viscoelasticity .....	21
2.1.4 Influence of Structure on Applied Stress and Strain .....	23
2.2 Theory of Stress Relaxation .....	26
2.2.1 Physical Contributions to Stress Relaxation .....	26
2.2.2 Chemical Contributions to Stress Relaxation.....	27
2.2.3 Relationship between Creep and Stress Relaxation .....	28
2.3 Factors Influencing Stress Relaxation of Elastomers.....	28
2.3.1 The Influence of Fillers .....	29
2.3.2 Influence of Crosslink Density.....	32
2.3.3 Vulcanisation System.....	32
2.3.4 Change in Network Structure .....	34
2.3.5 Thermo-oxidative Degradation .....	35
<b>Chapter 3 Viscoelastic Modelling</b> .....	<b>38</b>
3.1 Maxwell Model .....	39
3.2 Voigt Model .....	43
3.3 Standard Linear Solid Model .....	45
3.4 Maxwell-Wiechert Model .....	46
3.5 Kelvin-Voigt Model .....	48
3.6 Relaxation and Retardation Spectra .....	48
<b>Chapter 4 Standard Lifetime Prediction Methods</b> .....	<b>50</b>
4.1 Time-Temperature Superposition Principle .....	50
4.2 Williams-Landel-Ferry Concept .....	52
4.3 The Arrhenius Extrapolation .....	54
4.4 Limitations to ISO standard .....	56
<b>Chapter 5 Materials and Experimental Methods</b> .....	<b>58</b>
5.1 Materials .....	58
5.2 Continuous Compression Stress Relaxation .....	60



5.3	Discontinuous Stress Relaxation Measurements.....	66
5.4	Relaxation Spectroscopy .....	68
5.4.1	Dynamic Mechanical Analysis.....	69
5.4.2	Dielectric Spectroscopy.....	70
5.5	Change in Crosslink Density and Structure during Ageing .....	71
5.5.1	Determination of Crosslink Type .....	72
5.6	Chemiluminescence .....	74
<b>Chapter 6</b>	<b>Factors which Influence Stress Relaxation Behaviour .....</b>	<b>77</b>
6.1	Influence of Filler and Crosslink Density .....	77
6.2	Influence of Dispersion .....	80
6.3	Vulcanisation System.....	81
6.4	Network Structure Investigations.....	83
6.5	Investigation into the Influence of Oxidation .....	86
6.7	Compression Rate .....	90
6.8	Oxidation Evaluation by means of Chemiluminescence.....	91
6.9	Conclusion of Chapter 6.....	96
<b>Chapter 7</b>	<b>Lifetime Prediction.....</b>	<b>98</b>
7.1	Time-Temperature Superposition Principle .....	98
7.1.1	Application of Superposition to Dynamic Mechanical Data .....	102
7.1.2	Application of Superposition to Dielectric Measurements .....	104
7.2	Williams-Landel-Ferry Principle .....	106
7.3	Application of ISO Standard Arrhenius Extrapolation .....	110
7.3.1	Application of the ISO/Arrhenius Concept for Predictions .....	111
7.4	Discussion and Conclusions concerning TTSP, WLF and Arrhenius .....	114
<b>Chapter 8</b>	<b>Spectral Analysis .....</b>	<b>117</b>
8.1	Non-linear Regularisation Validation .....	117
8.2	Spectral Analysis of Experimental Relaxation Data .....	121
8.3	Spectral Analysis and Evaluation of Activation Parameters.....	124
8.4	Interpretation of Spectral Analysis Investigation.....	137
<b>Chapter 9</b>	<b>Conclusion.....</b>	<b>139</b>
9.1	Factors Influencing Stress Relaxation.....	139
9.2	Standard Lifetime Prediction Methods .....	141
9.3	Spectral Analysis.....	142
<b>Chapter 10</b>	<b>Outlook.....</b>	<b>145</b>
<b>Glossary of Terms .....</b>		<b>146</b>
<b>References .....</b>		<b>149</b>
<b>Appendices .....</b>		<b>155</b>
Appendix 1 – Examples of NR master-curve mismatching.....		156
Appendix 2 – A List of Published Papers Relevant to the Research .....		159
Appendix 3 – KHK Poster Award .....		162

## List of Figures

Figure 2.1:	Temperature dependency of an amorphous polymer .....	22
Figure 2.2:	2D diagram of polymer chains crosslinked into a network .....	24
Figure 2.3:	(a) Undeformed elastomer and (b) in uniaxial tension .....	24
Figure 2.4:	Electron microscope image of CB and surface representation.....	29
Figure 2.5:	Sulphur bonds schematic .....	33
Figure 3.1:	(a) Spring element and (b) Dashpot element .....	38
Figure 3.2:	Maxwell model .....	39
Figure 3.3:	Inflection point representing relaxation time $\tau$ .....	40
Figure 3.4:	Strain and stress history of stress relaxation.....	42
Figure 3.5:	Voigt model .....	43
Figure 3.6:	Strain and stress history of a creep experiment .....	44
Figure 3.7:	A Standard linear solid model .....	46
Figure 3.8:	Maxwell-Wiechert model .....	46
Figure 3.9:	Two component Maxwell-Wiechert model in stress relaxation...	47
Figure 3.10:	Kelvin-Voigt model .....	48
Figure 4.1:	Master-curve construction (reference temperature 25°C) .....	51
Figure 4.2:	WLF plot .....	53
Figure 4.3:	Material property against time.....	55
Figure 4.4:	Arrhenius plot and life prediction.....	55
Figure 5.1:	Elastocon relaxation apparatus .....	62
Figure 5.2:	Stress relaxation test apparatus.....	63
Figure 5.3:	Spring effect compensation .....	64
Figure 5.4:	Discontinuous test jig cross-section and exploded view .....	67
Figure 5.5:	Force-displacement curve of discontinuous measurement.....	68
Figure 5.6:	Dynamic mechanical analysis (RSAII) .....	69
Figure 5.7:	Experimental set-up of the broadband dielectric spectrometer ....	71
Figure 5.8:	Schematic of chemiluminescence test machine .....	75
Figure 5.9:	Typical CL analysis curve .....	76
Figure 6.1:	Influence of filler type and content and XLD at 23°C .....	79
Figure 6.2:	Influence of filler type and content and XLD at 70°C .....	80
Figure 6.3:	Influence of filler dispersion at 100°C .....	81
Figure 6.4:	Comparison between NR1 and NR7 at 100°C .....	82
Figure 6.5:	Crosslink network change during ageing (NR1) .....	83
Figure 6.6:	Crosslink structure change during ageing (NR7) .....	84
Figure 6.7:	Crosslink structure change (%) .....	85
Figure 6.8:	Exponential decay of polysulphidic bonds ( $S_x$ ).....	85
Figure 6.9:	Set-up with air inlet (a), without air inlet (b), stretched (c).....	87
Figure 6.10:	“Stretched o-ring” compression plates .....	88
Figure 6.11:	Comparison of unstretched and stretched at O-ring at 180°C.....	89
Figure 6.12:	Comparison of unstretched and stretched at O-ring at 150°C.....	89
Figure 6.13:	Varying compression rate of NR1 .....	91
Figure 6.14:	CL analysis and OIT evaluation of NR .....	92
Figure 6.15:	NR Stress relaxation data at 100°C, 120 °C and 150 °C.....	93
Figure 6.16:	NR stress relaxation data 100°C, 120 °C and 150 °C .....	94
Figure 7.1:	Stress relaxation data of NR7 .....	99
Figure 7.2:	TTSP master-curve of NR7 at $T_{ref} = 23^\circ\text{C}$ .....	100
Figure 7.3:	Master-curve of NR1 at $T_{ref} = 23^\circ\text{C}$ .....	101

Figure 7.4:	Unshifted DMA data (a) and master-curve at $T_{ref} = 23^{\circ}C$ (b) (NR7)	102
Figure 7.5:	NR1 master-curve at $T_{ref} = 23^{\circ}C$	103
Figure 7.6:	Frequency and temperature dependent dielectric loss $\epsilon''$	105
Figure 7.7:	NR1 dielectric master-curve	106
Figure 7.8:	Shift factor comparison of SR, DMA and dielectric data (NR1)	107
Figure 7.9:	EPDM stress relaxation data	108
Figure 7.10:	EPDM master-curve at $T_{ref} = 23^{\circ}C$	108
Figure 7.11:	EPDM master-curve of DMA data $T_{ref} = 23^{\circ}C$	109
Figure 7.12:	Shift factor comparison of SR, DMA and dielectric data (EPDM)	110
Figure 7.13:	NR1 Arrhenius lifetime prediction	111
Figure 7.14:	NR7 Arrhenius lifetime prediction	112
Figure 7.15:	EPDM Arrhenius lifetime prediction	113
Figure 7.16:	EPDM Arrhenius plot ( $F_t / F_{30}$ )	114
Figure 8.1:	Two process relaxation curve and relaxation spectrum	118
Figure 8.2:	Reduced data curve with resulting spectrum	120
Figure 8.3:	Scattered relaxation curve investigation	121
Figure 8.4:	Example of relaxation curve and spectrum - NR7 $120^{\circ}C$	121
Figure 8.5:	Relaxation data showing oscillating spectral curve	122
Figure 8.6:	Example of linear subtraction procedure – NR7 $120^{\circ}C$	123
Figure 8.7:	NR1 (CV) spectral analysis at $70^{\circ}C$	124
Figure 8.8:	NR1 (CV) spectral analysis at $100^{\circ}C$	125
Figure 8.9:	NR1 (CV) spectral analysis at $120^{\circ}C$	125
Figure 8.10:	NR1 (CV) Arrhenius plot	126
Figure 8.11:	Fitting of NR1 data at predictions at lower temperatures	128
Figure 8.12:	NR7 (SEV) spectral analysis at $70^{\circ}C$	129
Figure 8.13:	NR7 (SEV) spectral analysis at $100^{\circ}C$	129
Figure 8.14:	NR7 (SEV) spectral analysis at $120^{\circ}C$	130
Figure 8.15:	NR7 (SEV) Arrhenius plot	131
Figure 8.16:	Fitting of NR7 and predictions at lower temperatures	131
Figure 8.17:	Improved $120^{\circ}C$ fitting of NR7 using a two process spectrum	132
Figure 8.18:	CV / SEV comparison at $23^{\circ}C$	133
Figure 8.19:	EPDM spectral analysis at $100^{\circ}C$	133
Figure 8.20:	EPDM spectral analysis at $120^{\circ}C$	134
Figure 8.21:	EPDM spectral analysis at $150^{\circ}C$	134
Figure 8.22:	EPDM spectral analysis at $180^{\circ}C$	135
Figure 8.23:	EPDM Arrhenius plot	135
Figure 8.24:	Fitting of EPDM data and prediction at lower temperatures	136
Figure A1.1:	NR master-curve mismatching – NR 2	156
Figure A1.2:	NR master-curve mismatching – NR 3	156
Figure A1.3:	NR master-curve mismatching – NR 4	157
Figure A1.4:	NR master-curve mismatching – NR 5	157
Figure A1.5:	NR master-curve mismatching – NR 6	158

## List of Tables

Table 2.1:	First digit assignment to carbon black by ASTM.....	31
Table 5.1:	Natural rubber compounds (phr: parts per hundred rubber).....	59
Table 5.2:	Sulphur cured EPDM compound.....	60
Table 5.3:	Dynamic mechanical test parameters .....	70
Table 6.1:	Dispersion times (mins) of NR8 natural rubber compound .....	80
Table 8.1:	List of NR1 $\tau$ values determined by spectral analysis.....	126
Table 8.2:	Activation energy values of NR1 .....	127
Table 8.3:	List of NR 7 $\tau$ values determined by spectral analysis.....	130
Table 8.4:	Activation energy values of EPDM.....	136