



# CONTENTS

List of tables	IV
List of figures	X
List of symbols	XI
List of abbreviations	
<b>1.0 Introduction</b>	1
1.1 General Introduction	1
1.2 Research Objective	3
1.3 Outline of the Thesis	4
<b>2.0 Literature survey</b>	5
2.1 Background	5
2.2 Tire technology	6
2.2.1 History	6
2.2.2 Definition	6
2.2.3 Functions	6
2.2.4 Tire components	7
2.2.5 Tire nomenclature	9
2.2.6 Application of tire	9
2.3 Tire rolling resistance	10
2.4 Tire tread	11
2.4.1 Performance	11
2.4.2 Tread compound design	11
2.4.3 Requirements	12
2.4.4 Tread compound formulations	15
2.5 Fillers and reinforcement	16
2.5.1 Reinforcement	16

2.5.2	Characterization of rubber filler systems	17
2.5.3	Carbon black filler	21
2.5.4	Silica fillers	22
2.5.5	Nanoclay (Na-montmorillonite)	24
2.5.6	Organoclay (organic layer silicate)	26
2.6	Nanocomposites	27
2.6.1	Nano materials	27
2.6.2	Polymer and rubber nanocomposite	27
2.7	Finite element tire simulation and rolling resistance prediction of tire	31
2.8	Scope of the work	33
<b>3.0</b>	<b>Materials &amp; methods</b>	<b>37</b>
3.1	Raw materials	37
3.1.1	Raw material descriptions	37
3.1.2	Natural rubber (NR)	38
3.1.3	Emulsion styrene butadiene rubber (ESBR)	40
3.1.4	Solution styrene butadiene rubber (SSBR)	41
3.1.5	Functionalized solution SBR (FSSBR)	41
3.1.6	Polybutadiene rubber (BR)	42
3.1.7	Nitrile rubber (NBR) and carboxylated NBR (XNBR)	43
3.1.8	Organoclay (Cloisite <sup>®</sup> 15A)	44
3.1.9	Carbon black (ISAF-N220)	45
3.1.10	Highly dispersible silica (HDS)	46
3.1.11	Silane coupling agent	46
3.1.12	Antidegradant	47
3.1.13	Sulfenamide accelerator (TBBS)	48
3.1.14	Diphenyl guanidine (DPG)	49
3.1.15	Rhombic sulphur	49

3.1.16	Zinc oxide	50
3.1.17	Stearic acid	51
3.2	Mixing and preparation of nanocomposites	52
3.2.1	Mixing equipments	52
3.2.2	Preparation of organoclay-XNBR master batch	53
3.2.3	Preparation of SBR/BR & NR/BR-organoclay nanocomposites	53
3.2.4	Preparation on SBR/BR & NR/BR -dual fillers nanocomposites	54
3.3	Experimental designs	54
3.3.1	SBR/BR-organoclay nanocomposites	54
3.3.2	NR/BR - organoclay nanocomposites	56
3.4	Compound formulations	57
3.4.1	SBR/BR-organoclay nanocomposites formulations	57
3.4.2	Compound formulations of SBR/BR-dual fillers nanocomposites	58
3.4.3	NR/BR-organoclay nanocomposites formulations	59
3.4.3	Compound formulations of NR/BR-dual fillers nanocomposites	59
3.5	Material testing and characterization	60
3.5.1	Rheological properties	60
3.5.2	Sample preparation	61
3.5.3	Rubber specimens for mechanical & dynamic test	61
3.5.4	Stress-strain properties	62
3.5.5	Tear properties	62
3.5.6	Hardness test	62
3.5.7	DIN abrasion test	63
3.5.8	Heat build up test	63
3.5.9	Dynamic mechanical test	64
3.5.10	Filler characterization	64
3.5.11	X-ray diffraction (XRD)	65

3.5.12	Transmission electron microscopy (TEM)	65
3.6	Material parameter identification for FE tire simulation	66
3.7	Rolling resistance experiment	66
3.7.1	Passenger car radial (PCR) tire	66
3.7.2	Truck bus radial (TBR) tires	67
<b>4.0</b>	<b>Development and characterization of nanocomposites for passenger car radial tire tread application</b>	<b>68</b>
4.1	Preparation and characterization of nanocomposites based on organoclay and blends of different types of SBR with BR	68
4.1.1	Introduction	68
4.1.2	Rheometric properties	69
4.1.3	Mechanical properties	71
4.1.3.1	Effect of carboxyl content of compatibilizer in nanocomposite.	71
4.1.3.2	Effect of mixing techniques	73
4.1.3.3	Compatibilizer (XNBR) and filler (organoclay) dose optimization	75
4.1.3.4	Effect of type of SBR	75
4.1.4	Viscoelastic properties	77
4.1.5	X-Ray Diffraction Study	79
4.1.6	Transmission Electron Microscopy	79
4.1.7	Conclusions	81
4.2	Development and characterization of high performance nanocomposites based on dual filler system and blends of different types of SBR with BR.	82
4.2.1	Introduction	82
4.2.2	Filler characterization	83
4.2.3	Rheometric properties	84
4.2.4	Mechanical properties	85
4.2.5	Viscoelastic properties	87
4.2.6	X-Ray diffraction study	92

4.2.7	Transmission electron microscopy	94
4.2.8	Conclusions	95
<b>5.0</b>	<b>Preparation and characterization of NR/BR nanocomposites for truck bus radial (TBR) tire tread application</b>	<b>97</b>
5.1	Preparation and characterization of nanocomposites based on NR/BR blends and organoclay	97
5.1.1	Introduction	97
5.1.2	Rheometric properties	98
5.1.3	Mechanical properties	100
5.1.4	Dynamic mechanical properties	102
5.1.5	X-Ray diffraction (XRD)	104
5.1.6	Transmission electron microscopy (TEM)	105
5.1.7	Conclusions	106
5.2	Development and characterization of high performance nanocomposites based on NR/BR blends and dual filler system	107
5.2.1	Introduction	107
5.2.2	Filler characterization and dispersion	108
5.2.3	Rheometric properties	109
5.2.4	Mechanical properties	109
5.2.5	Viscoelastic properties	112
5.2.6	X-Ray diffraction (XRD) study	114
5.2.7	Transmission electron microscopy (TEM) study	116
5.2.8	Conclusions	119
<b>6.0</b>	<b>Rolling resistance simulation of tires using static finite element analysis (FEA)</b>	<b>120</b>
6.1	Elastic Tire Simulation using FEA	121
6.1.1	Finite element model generation	121
6.1.2	Material properties	122

6.1.3	Material modeling	123
6.1.4	Steady state rolling simulation	125
6.2	Rolling resistance software development	125
6.2.1	Introduction	125
6.2.2	Prediction of tire RR and temperature distributions	126
6.2.3	The methodology used in RR code development	127
6.2.4	Computation of energy dissipation & rolling resistance	129
6.2.5	Temperature equation	130
6.2.6	Temperature distribution in a tire	132
<b>7.0</b>	<b>Prediction of rolling resistance of PCR and TBR tires with nanocomposite treads using finite element tire simulation</b>	<b>134</b>
7.1	Investigations on rolling resistance of nanocomposite based passenger car radial tire tread compounds using FE simulation technique	135
7.1.1	Mechanical properties	136
7.1.2	Hyper-elastic material properties	137
7.1.3	Viscoelastic material properties	139
7.1.4	Computation of rolling resistance	139
7.1.5	Conclusions	142
7.2	Investigations on rolling resistance of nanocomposite based truck bus radial tire tread compounds using FE Simulation Technique	143
7.2.1	Mechanical properties	143
7.2.2	Hyper-elastic material properties	144
7.2.3	Viscoelastic material properties	146
7.2.4	Computation of rolling resistance	146
7.2.5	Conclusions	152
<b>8.0</b>	<b>Summary and conclusions</b>	<b>154</b>
	<b>References</b>	<b>163</b>