

LIST OF FIGURES



2.1	Tire axis system and characteristics	
2.2	Passenger car radial (PCR) tire construction	8
2.3	Truck bus radial (TBR) tire construction	8
2.4	Tire applications in different areas	9
2.5	Forces acting on tires	10
2.6	Magic triangle of PCR tread compound	12
2.7	Contribution of tire components towards rolling resistance in PCR tire	13
2.8	Contribution of tire components towards rolling resistance in TBR tire	13
2.9	EU legislation on tire labeling	14
2.10	The world wide tire labeling	14
2.11	EU classification for PCR tire rolling resistance	14
2.12	Payne's effect	17
2.13	Calculation of free energy, work of adhesion and filler flocculation	17
2.14	Calculation of surface energy	18
2.15	Surface energy of fillers	19
2.16	Surface energy of rubbers	19
2.17	Free energy of immersion of rubbers and fillers	20
2.18	Calculation of work of adhesion	20
2.19	Calculation of filler flocculation	21
2.20	Carbon black structure	21
2.21	SEM image of carbon black	21
2.22	Structures in filled rubbers on different length scales	22
2.23	ECOREX, Nano structures CB and Standard CB	22
2.24	Silica-silane reaction	24
2.25	Structure of montmorillonite (MMT) nanoclay	25

2.26	SEM image of bentonite clay	25
2.27	TEM image of MMT	25
2.28	XRD patterns of organoclay (Cloisite 15A [®]) and Na-MMT	26
2.29	Chemical structure of different nano particles	27
2.30	Intercalated and exfoliated structure of rubber nanocomposite	28
3.1	Chemical structure of NR	39
3.2	Heavea Brasiliensis tree and trapping	39
3.3	Chemical structure of SBR	40
3.4	Micro and macrostructure of Co-BR	43
3.5	Micro and macrostructure of NBR	43
3.6	Chemical structure of organoclay	44
3.7	Chemical structure of Si 69 [®]	47
3.8	Chemical structure of 6PPD	47
3.9	Chemical structure of TBBS	48
3.10	Chemical structure of 1, 3-Diphenylguanidine (DPG)	49
3.11	Chemical structure of rhombic sulphur (S ₈)	50
3.12	Particle size distribution	50
3.13	Particle morphology	50
3.14	Stearic acid molecule	51
3.15	Laboratory Banbury	53
3.16	Two roll mill	53
3.17	Schematic diagram of experimental design of SBR/BR and clay nanocomposite	55
3.18	Schematic diagram of experimental design of “NR/BR and clay” nanocomposite	56
3.19	MDR 2000E	60
3.20	Hydraulic curing press	61
3.21	Hollow die punch	61

3.22	Rubber specimens for mechanical and dynamic test	62
3.23	Zwick UTM	63
3.24	Hardness tester	63
3.25	Zwick DIN abrader	63
3.26	BF Goodrich flexometer	64
3.27	Viscoanalyse VA 400	64
3.28	Particle size analyzer	64
3.29	Tire rolling resistance measurement equipment	67
4.1	PCR Tire	68
4.2	Effect of carboxylation on stress-strain properties	72
4.3	Effect of % carboxyl group on T.S	72
4.4	Effect of % carboxyl group on E.B	72
4.5	Effect of % carboxyl group on breaking energy	74
4.6	Effect of different mixing techniques on stress-strain properties of nanocomposites	74
4.7	Comparative properties of different mixing techniques	74
4.8	Optimization of Clay and XNBR dosages in nanocomposite	75
4.9	Tan delta versus temperature of SSBR - Gum compounds and nanocomposites	78
4.10	Tan delta versus temperature of ESBR - Gum compounds and nanocomposites	78
4.11	XRD graph of clay (OC), SSBR/BR gum (G2) and SSBR/BR –organoclay nanocomposite (R2)	78
4.12	TEM image of nanocomposite (M1) prepared in 2 roll mill.	80
4.13	TEM image of nanocomposite (M2) prepared by solution mixing method	80
4.14	TEM image of nanocomposite (M3) prepared by internal mixer	80
4.15	Particle size distribution of carbon black, silica and nanoclay	84
4.16	Stress-strain properties of nanocomposites based on ESBR/BR blend and organoclay-carbon black dual filler	86

4.17	Stress-strain properties of nanocomposites based on SBR/BR blend with organoclay-silica dual filler	86
4.18	Storage modulus versus temperature	89
4.19	SBR/BR dual filler nanocomposite: Loss modulus versus temperature	89
4.20	Tangent delta versus temperature	89
4.21	Strain sweep at 10 Hz and 60°C: Shear modulus versus strain of Control compounds	91
4.22	Strain sweep at 10 Hz and 60°C: Shear modulus versus strain of nanocomposites	91
4.23	Strain sweep at 10 Hz and 60°C: Tan δ versus strain of Control compounds	91
4.24	Strain sweep at 10 Hz and 60°C: Tan δ versus strain of Control compounds	92
4.25	XRD graph-Organoclay, Gum rubber and Nanocomposites	92
4.26	TEM image of SBR/BR-organoclay nanocomposite (SOC-6)	94
4.27	TEM image of ESR/BR and organoclay-carbon black dual filler system nanocomposite (EC-25)	94
4.28	TEM image of ESR/BR and organoclay-silica dual filler nanocomposite (ES-25)	94
4.29	TEM image of SBR/BR and organoclay-silica dual filler nanocomposite (SS-25)	94
5.1	10.00R20 TBR Tire	97
5.2	Effect of carboxyl % in XNBR on stress strain properties of nanocomposites	101
5.3	Effect of mixing techniques on stress-strain properties on nanocomposites	101
5.4	Effect of organoclay dosages on stress strain properties of nanocomposites	101
5.5	Dynamic mechanical property: storage modulus versus temperature	103
5.6	Dynamic mechanical property: loss modulus versus temperature	103
5.7	Dynamic mechanical property: Tan δ versus temperature	103
5.8	X-ray diffraction patterns of the organoclay, Gum compound and nanocomposite with 7 phr organoclay	104

5.9	TEM images of nanocomposite with 7 phr organoclay	106
5.10	(A) Organoclay-carbon black and (B) Organoclay-silica filler dispersion	108
5.11	Stress-strain properties of Control-3, organoclay and organoclay –carbon black dual filler nanocomposites	110
5.12	Stress-strain properties: Control-4, organoclay and organoclay –silica dual filler nanocomposites	110
5.13	Shear storage modulus versus strain at 60°C	113
5.14	Shear loss modulus versus strain at 60°C	113
5.15	Tan δ versus strain at 60°C	113
5.16	XRD of organoclay and dual filler nanocomposites	115
5.17	TEM images of NR/BR organoclay nanocomposites (NM-7)	116
5.18	TEM images of NR/BR organoclay-carbon black nanocomposites (NC 20)	117
5.19	TEM images of NR/BR organoclay-silica nanocomposites (NS 20)	118
6.1	Simulated PCR tire foot print	120
6.2	PCR tire geometry: half tire cross section	122
6.3	TBR tire geometry: half tire cross section	122
6.4	Hyper-elastic material models for NR/BR dual filler (organoclay-carbon black) nanocomposite	124
6.5	Marlow’s model for Nylon 66 tire cord	124
6.6	Marlow’s material model for steel cord reinforcement	125
6.7	Flow diagram of prediction of tire rolling resistance using FEA	126
6.8	Tire cross section and elemental ring along the circumference	128
6.9	Stress-strain relationship of viscoelastic materials under cyclic loading-phase lag between stress and strain	128
6.10	Transformation of Non harmonic to harmonic function using Fourier Series	129
6.11	Maxwell model: rubber is represented by spring and dashpot	130
6.12	Hysteresis loop of viscoelastic materials under cyclic loading.	131
6.13	Strain versus Tan δ at 10 Hz	132

6.14	Element and integration points in a PCR tire cross-section	133
6.15	Temperature distribution in a TBR tire cross-section	133
7.1	TBR tire RR measurement	134
7.2	PCR tire Speed versus RR	134
7.3	PCR tire model with meshing	135
7.4	Hyperelastic stress-strain properties of nanocomposites and Control compounds	138
7.5	Tan δ versus strain at 10 Hz and 60°C	138
7.6	2D Finite element tire (205/65R15) cross section	140
7.7	Footprint of PCR tire (A) with silica based commercial tread compound (Control-1) and (B) with organoclay-silica dual filler nanocomposite (SS-25) tread compound	140
7.8	Simulated TBR half tire model	143
7.9	Hyperelastic properties of TBR tread rubber compounds	145
7.10	Tan δ versus strain (SSA) at 60°C	145
7.11	RR results- measurement versus simulation	147
7.12	Footprint of 10.00 R20 TBR tire with commercial carbon black tread (M) simulated footprint and (N) measured footprint	147
7.13	TBR tire (10.00R20) 2D full tire cross section	148
7.14	TBR tire (295/80R22.5) 2D half tire cross section	148
7.15	Footprint of 295/80R22.5 TBR tire (S) with commercial carbon black tread, Control-3 and (T) with organoclay-carbon black nanocomposite tread, NC-20.	149
7.16	RR results: Organoclay-carbon black nanocomposite	150
7.17	RR results: Organoclay-silica nanocomposite	150