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Modeling of Contact Length for Radial-Ply Tire Based on Section Width, Overall Unloaded Diameter, Inflation Pressure, Vertical Load and Rotational Speed

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Abstract: This study was conducted to model contact length (L) of radial-ply tire based on section width (b), overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N). For this reason, contact length of three radial-ply tires with different section width and overall unloaded diameter were measured at three levels of inflation pressure, four levels of vertical load and six levels of rotational speed. In order to model contact length based on section width, overall unloaded diameter, inflation pressure and vertical load, a five-variable linear regression model was suggested and all the data were subjected to regression analysis. The statistical results of study indicated that the five-variable linear regression model L = 559.7 - 0.059 b - 0.651 d - 2.930 P + 0.320 W - 0.009 N with R^2 = 0.9715 may be suggested to predict contact length of radial-ply tire based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of radial-ply tire sizes.

Key words: Radial-ply tire · Contact length · Section width · Overall unloaded diameter · Inflation pressure · Vertical load · Rotational speed · Modeling

INTRODUCTION

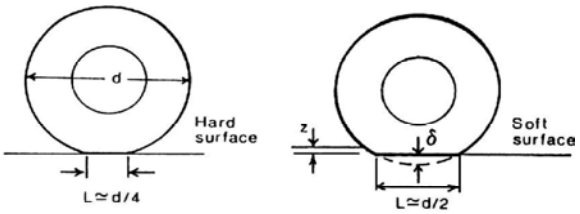
A flexible tire has a smaller contact area on hard surface than it dose on soft ground. A rule of thumb which can be used for estimation of tire contact area is shown by equation 1 [1]:

$$A = bL \quad (1)$$

Where:

A = Contact area of tire (m^2)
b = Section width of tire (m)
L = Contact length of tire (m)

McKyes [1] gave an approximate method for estimating contact length of tire on hard and soft surfaces (Fig. 1) as given below in equations 2 and 3, respectively:



Fg. 1: Contact lengths of tires on hard and soft surfaces, adapted from McKyes [1]

$$L = \frac{d}{4} \text{ (On a hard surface)} \quad (2)$$

$$L = \frac{d}{2} \text{ (On a soft surface)} \quad (3)$$

Where:

d = Overall unloaded diameter of tire (m)

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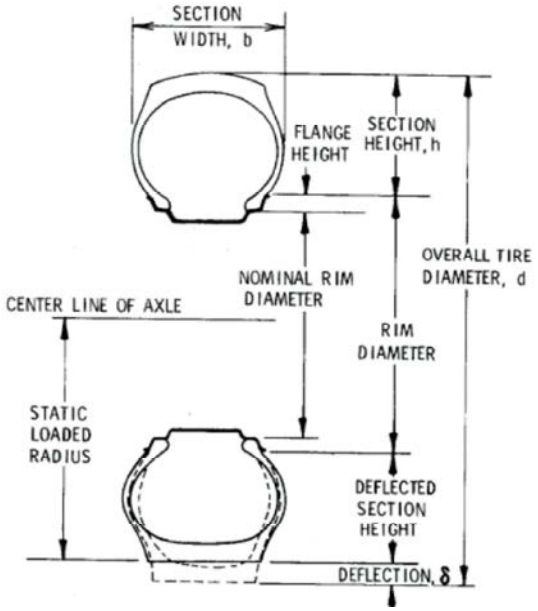

Fig. 2: Tire dimensions, adapted from Brixius [4]

Moreover, Wong [2] and Bekker [3] gave an approximate method for calculating contact length of tire as given below in equation 4:

$$L = 2(d\delta - \delta^2)^{0.5} \quad (4)$$

Where:

δ = Deflection of tire (m)

Tire contact length is a key parameter and many equations have been developed based on tire contact length to evaluate the tractive performance of radial-ply and bias-ply tires operating in cohesive-frictional soils. Gross traction, motion resistance, net traction and tractive efficiency are predicted as a function of soil strength, tire load, tire slip, tire size, tire deflection and tire contact length [4]. Fig. 2 shows the tire dimensions (b, d and δ) used. The tire dimensions can be obtained from tire data book or by measuring the tire. The section width (b) is the first number in a tire size designation. The overall unloaded diameter (d) can be obtained from the tire data handbooks available from off-road tire manufacturers. The tire deflection (δ) on a hard surface is equal to d/2 minus the measured static loaded radius. The static loaded radius for the tire's rated load and inflation pressure is standard tire data from the tire data handbooks. It can also be obtained by measuring the tire [4, 5].

As contact length for a given tire size, inflation pressure, vertical load and rotational speed may significantly be different between radial-ply and bias-ply tires, this study was conducted to model contact length (L) of radial-ply tire based on section width (b), overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N) using a linear regression model.

MATERIALS AND METHODS

Tire Contact Length Test Apparatus: A tire contact length test apparatus was designed and constructed to measure contact length of tires with different sizes at diverse levels of inflation pressure, vertical load and rotational speed (Fig. 3).

Experimental Procedure: For this purpose, contact length of three radial-ply tires with different section width and overall unloaded diameter were measured at three levels of inflation pressure, four levels of vertical load and six levels of rotational speed. The section width and overall unloaded diameter of three radial-ply tires are given in Table 1. Results of contact length measurement for radial-ply tires No. 1, 2 and 3 are given in Tables 2, 3 and 4, respectively.

Regression Model: A typical five-variable linear regression model is shown in equation 5 [6-11]:

$$Y = C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \quad (5)$$

Where:

Y = Dependent variable, for example contact length of radial-ply tire

X_1, X_2, X_3, X_4, X_5 = Independent variables, for example section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed

C_0, C_1, C_2, C_3, C_4, C_5 = Regression coefficients

To model contact length based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed, a five-variable linear regression model was suggested.

Table 1: Section width and overall unloaded diameter of three radial-ply tires used in this study

Tire No.	Section width b (mm)	Overall unloaded diameter d (mm)
1	175	578
2	195	582
3	185	605

Table 2: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 1

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
175	578	30	100	0	121	121	120
				600	115	115	115
				700	114	114	114
				800	113	113	112
				900	112	112	111
				1000	111	111	111
			150	0	138	138	137
				600	131	131	130
				700	130	130	130
				800	128	128	129
				900	127	127	127
				1000	126	126	126
			200	0	148	148	147
				600	141	141	141
				700	140	140	140
				800	139	139	139
				900	138	138	137
				1000	137	137	137
			250	0	157	157	157
				600	151	151	150
				700	150	150	150
				800	149	149	149
				900	148	148	148
				1000	147	147	147
		35	100	0	104	103	103
				600	97	97	97
				700	96	96	96
				800	95	95	95
				900	94	94	94
				1000	93	93	93
			150	0	122	122	122
				600	116	117	116
				700	115	115	115
				800	113	112	113
				900	111	110	111
				1000	109	109	109
			200	0	139	139	139
				600	135	135	135
				700	134	134	134
				800	133	133	133
				900	132	132	132
				1000	131	132	131
			250	0	151	150	151
				600	146	146	146
				700	145	145	145
				800	144	144	144
				900	143	143	143
				1000	142	142	142

Table 2: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
		40	100	0	86	87	86
				600	83	82	83
				700	82	82	82
				800	80	80	80
				900	78	78	79
				1000	77	77	76
			150	0	104	104	105
				600	99	99	100
				700	98	97	97
				800	96	95	95
				900	93	94	93
				1000	91	91	91
			200	0	125	125	125
				600	119	119	119
				700	118	117	117
				800	116	116	116
				900	115	115	115
				1000	114	115	114
			250	0	134	134	134
				600	128	127	128
				700	126	126	126
				800	125	125	125
				900	124	124	124
				1000	123	123	123

Table 3: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 2

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
195	582	30	100	0	110	110	110
				600	104	104	103
				700	102	102	101
				800	100	100	99
				900	99	99	99
				1000	98	98	98
			150	0	129	129	129
				600	125	125	125
				700	124	124	124
				800	123	123	122
				900	122	122	122
				1000	121	121	120
			200	0	151	151	151
				600	148	148	147
				700	147	147	146
				800	147	147	146
				900	146	146	145
				1000	145	145	145
			250	0	168	168	168
				600	164	164	163
				700	163	163	162
				800	162	162	161
				900	161	161	160
				1000	160	160	160

Table 3: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
		35	100	0	95	95	95
				600	90	90	89
				700	89	89	89
				800	87	87	87
				900	86	86	86
				1000	85	84	84
			150	0	114	114	114
				600	100	100	101
				700	98	98	98
				800	97	97	97
				900	96	96	97
				1000	95	95	95
			200	0	130	130	130
				600	126	126	126
				700	125	125	124
				800	124	123	123
				900	123	122	122
				1000	121	121	121
			250	0	140	140	140
				600	137	137	136
				700	136	136	135
				800	135	135	135
				900	135	135	134
				1000	134	134	133
		40	100	0	87	87	87
				600	82	82	81
				700	81	81	80
				800	80	80	79
				900	79	79	78
				1000	78	78	78
			150	0	105	105	105
				600	99	99	98
				700	98	98	97
				800	97	97	96
				900	96	96	95
				1000	95	95	94
			200	0	117	117	117
				600	113	113	112
				700	112	112	111
				800	111	111	110
				900	110	110	109
				1000	109	109	108
			250	0	132	132	132
				600	126	126	126
				700	126	126	125
				800	125	125	124
				900	124	124	123
				1000	123	123	123

Table 4: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 3

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
185	605	30	100	0	99	99	99
				600	93	93	92
				700	92	92	91
				800	91	91	90
				900	90	90	89
				1000	89	89	88
			150	0	116	116	116
				600	111	111	110
				700	110	110	109
				800	109	109	108
				900	108	108	107
				1000	107	107	106
			200	0	130	130	130
				600	127	127	126
				700	126	126	125
				800	125	125	124
				900	124	124	123
				1000	123	123	124
			250	0	149	149	149
				600	144	144	143
				700	143	143	142
				800	142	142	141
				900	141	141	140
				1000	140	140	139
		35	100	0	80	80	80
				600	76	76	75
				700	75	75	74
				800	74	74	73
				900	73	73	72
				1000	72	72	72
			150	0	100	100	100
				600	94	94	93
				700	93	93	92
				800	92	92	91
				900	91	91	90
				1000	90	90	89
			200	0	118	118	118
				600	113	113	112
				700	112	112	111
				800	111	111	110
				900	110	110	109
				1000	109	109	108
			250	0	131	131	131
				600	128	128	128
				700	128	128	128
				800	127	127	127
				900	127	127	127
				1000	126	126	126
		40	100	0	73	73	73
				600	67	67	66
				700	66	66	65
				800	65	65	64
				900	64	64	63
				1000	63	62	63

Table 4: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	sRotational speed N (rev/min)	Contact length L (mm)		
					L_1	L_2	L_3
			150	0	87	87	87
				600	84	84	84
				700	84	84	83
				800	83	83	83
				900	83	83	82
				1000	82	82	82
			200	0	98	98	98
				600	95	95	95
				700	94	94	94
				800	94	94	93
				900	93	93	93
				1000	93	93	92
			250	0	109	109	109
				600	108	107	107
				700	107	107	106
				800	106	106	106
				900	106	106	105
				1000	105	105	105

Fig. 3: Tire contact length measurement apparatus

RESULTS AND DISCUSSION

In order to model contact length of radial-ply tire based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed, a five-variable linear regression model was suggested and all the data were subjected to regression analysis using the Microsoft Excel 2007. The five-variable linear regression model, p-value of independent variables and coefficient of determination (R^2) of the model are shown in Table 5. As it is shown in Table 5, this model has a high R^2 value at 0.9715, indicating good agreement of the experimental data. In addition, the p-value of independent variables (b, d, P, W and N) is as follows: 0.002371, 1.7E-219, 0, 0 and 5.00E-66, respectively. Thus, based on the statistical results, this model is initially accepted, which is given by equation 6:

Table 5: Five-variable linear regression model, p-value of independent variables and coefficient of determination (R^2)

Model	p-value					R^2
	b	d	P	W	N	
L = 559.7 - 0.059 b - 0.651 d - 2.930 P + 0.320 W - 0.009 N	0.002371	1.7E-219	0	0	5.00E-66	0.9715

$$L = 559.7 - 0.059\,b - 0.651\,d - 2.930\,P + 0.320\,W - 0.009\,N \quad (6)$$

In this model, contact length of radial-ply tire can be predicted using five-variable linear regression of section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed.

CONCLUSIONS

It can be concluded that the five-variable linear regression model L = 559.7 - 0.059 b - 0.651 d - 2.930 P + 0.320 W - 0.009 N with R^2 = 0.9715 may be suggested to predict contact length of radial-ply tire based on

section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of radial-ply tire sizes.

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