T H E U N I V E R S I T Y O F M I C H I G A N

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Technical Report No. 15

TABLES OF ELASTIC CONSTANTS OF ORTHOTROPIC LAMINATES

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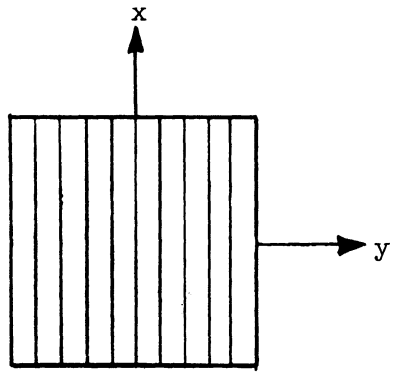
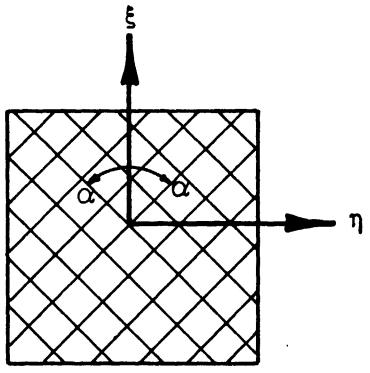
NOMENCLATURE

SINGLE SHEET OF FABRIC



E_x = modulus in x direction (cord direction)
E_y = modulus in y direction (perpendicular to cord)
F_{xy} = cross-modulus
G_{xy} = shear modulus

EVEN NUMBER OF LAMINATED FABRIC SHEETS



E_ξ = modulus in ξ direction
E_η = modulus in η direction
$F_{\xi\eta}$ = cross-modulus
$G_{\xi\eta}$ = shear modulus
α = cord half angle

I. FOREWORD

It has been shown in Ref. 1 that the elastic constants of orthotropic layered materials may be calculated in terms of a small number of parameters. This information is fundamental to a quantitative understanding of materials used in pneumatic tire construction, and is presented here in the hope that it will provide a convenient numerical guide to aid the ever-broadening applications of mechanics to the tire industry.

II. SUMMARY

A digital computer program described in Ref. 2 is used to solve the simultaneous equations relating stress and strain in an orthotropic two-dimensional sheet. From the solutions the elastic constants of the composite sheet may be determined. These are presented in dimensionless form over a range of variable encompassing all commonly used textile and wire fabric in rubber.

III. DETERMINATION OF ELASTIC CONSTANTS

The elastic constants of layered orthotropic laminates may be expressed in terms of the elastic constants of each layer and the angle at which the layers are oriented when assembled. For those cases where a single angle of assembly is chosen, and where each structure is built up of pairs of identical plies laminated together so that an even number of them always exists, it is possible to express the elastic constants of the total structure as a function of this angle and of the elastic constants of a single sheet of the material. This is the most common case encountered in the use of coated fabrics, and merits some detailed attention.

By means of certain simplifying assumptions, as discussed in Ref. 1, the elastic constants of a layered structure of the type described may be expressed as a function of the angle of assembly and of a dimensionless quantity representative of the degree of anisotropy of a single sheet of the fabric. Tabular data on these elastic characteristics of layered structures are presented, similar in form to those presented in Ref. 3, but with considerably more precision and in somewhat greater detail.

The primary difference between the graphical data of Ref. 3, and the tabular information presented here is that here the ratio G_{xy}/E_y is taken to be 0.25, instead of the value 0.333 used previously. In order to demonstrate that the former value is correct, consider the process of simple shear on a typical element of coated fabric in which

S = cord spacing
d = cord diameter
G_R = rubber modulus
δ = deflection
τ = shear stress

Referring to Fig. 1, and assuming the cords to be rigid compared to the rubber, the

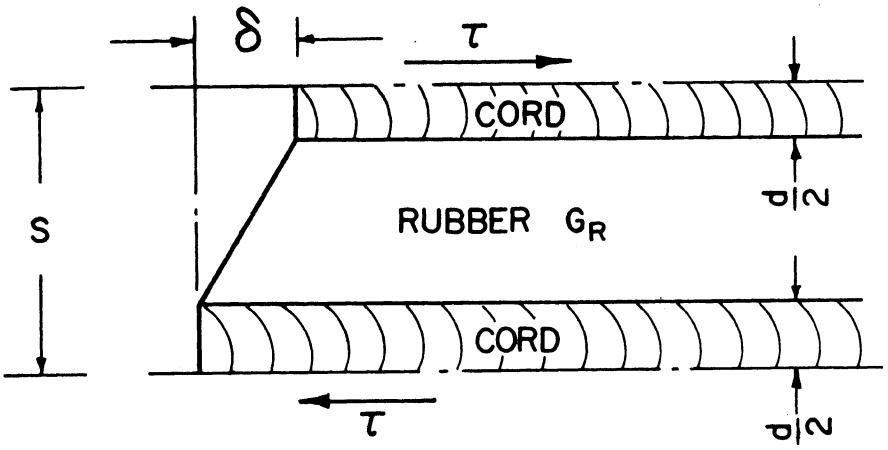


Fig. 1

effective shear strain over several cord lengths is given by

$$\gamma_{eff} = \frac{\delta}{S}$$

where

$$\delta = \frac{\tau}{G_R}(S - d)$$

Hence,

$$\gamma_{eff} = \frac{\tau}{G_R}\left(1 - \frac{d}{S}\right)$$

and the effective shear modulus of the composite is

$$G_{eff} = \frac{\tau}{\gamma_{eff}} = \frac{G_R}{\left(1 - \frac{d}{S}\right)} \qquad (1)$$

To find a similar expression for extension perpendicular to the cords, refer to Fig. 2 in which a similar geometry is shown. Here, stresses are applied causing

the rubber between cords to extend.

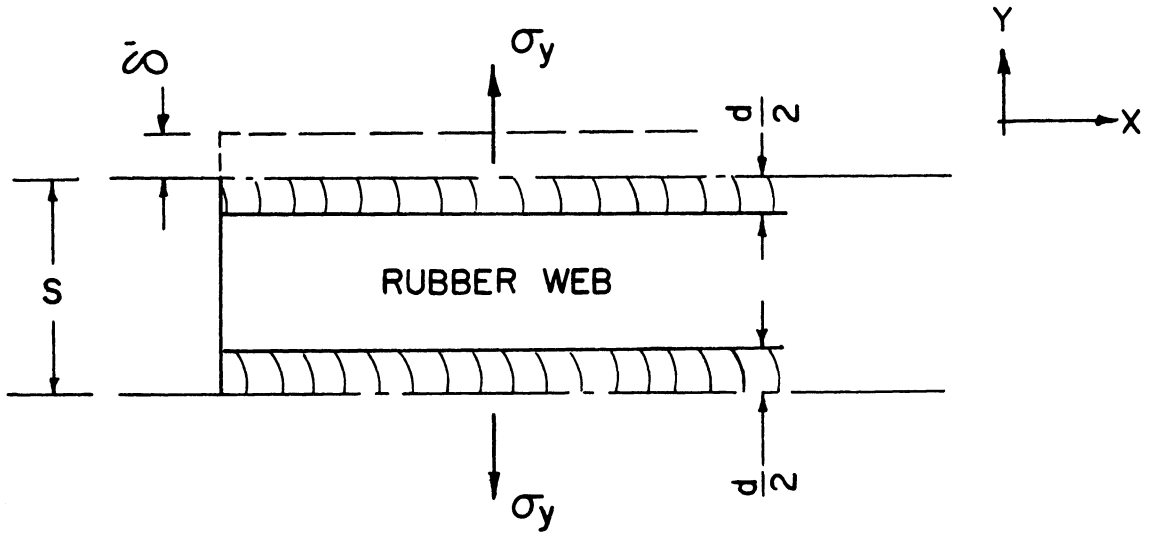


Fig. 2.

$$\delta' = \frac{\sigma_x}{E_{WEB}} (S - d)$$

But E_{WEB} must be determined using the fact that the web is prevented from contracting freely in the x direction due to the rigidity of the cords. For this, note that from Hooke's law, the strain in the x direction vanishes,

$$\epsilon_x = 0 = \frac{\sigma_x}{E_R} - \mu\frac{\sigma_x}{E_R}$$

$$\therefore \quad \frac{\sigma_x}{E_R} = \mu \frac{\sigma_x}{E_R}$$

In the y direction,

$$\epsilon_y = \frac{\sigma_y}{E_R} - \mu \frac{\sigma_x}{E_R} = \frac{\sigma_y}{E_R} (1 - \mu^2)$$

Hence the effective modulus of the web is

$$E_{WEB} = \frac{\sigma_x}{\epsilon_y} = \frac{E_R}{1 - \mu^2}$$

The mean, or effective, modulus of the composite is

$$E_{eff} = \frac{\sigma_y}{(\frac{\delta'}{S})} = \frac{E_{WEB}}{1 - \frac{d}{S}} = \frac{E_R}{(1 - \mu^2)} \cdot \frac{1}{(1 - \frac{d}{S})} \tag{2}$$

The ratio of effective moduli of the composite is

$$\frac{G_{eff}}{E_{eff}} = \frac{G_{xy}}{E_y} = \frac{G_R(1 - \mu^2)}{E_R} \tag{3}$$

But it is well known for linearly elastic materials that

$$G = \frac{E}{2(1 + \mu)} \tag{4}$$

Using Eq. (4) in Eq. (3) gives

$$\frac{G_{xy}}{E_y} = \frac{1 - \mu^2}{2(1 + \mu)} = (\frac{1 - \mu}{2}) \tag{5}$$

For an incompressible material such as rubber, $\mu = 0.5$ and

$$(\frac{G_{xy}}{E_y})_{\substack{\text{RUBBER} \\ \text{WEB}}} = 0.25 \tag{6}$$

In all of the subsequent data the ratio E_x/F_{xy} is taken to be 0.5. The origin of this numerical value is thoroughly discussed in Ref. 1.

The dimensionless quantity G_{xy}/E_x of a single sheet may be thought of as characterizing the degree of anisotropy of the sheet. It is a parameter used in these computations and is allowed to range over eight separate values so that interpolation can be performed readily where it is required.

The tables are presented using a notation borrowed from digital computer practice, in which all numbers are given as decimals, followed by a capital E, and in turn followed by a number representing the exponent of ten which should be used as a multiplier for the decimal number. For example, .123861E 3 should be read as 123.861 while .996865E-2 should be read as .00996865.

The symmetry properties of the elastic constants may be used to generate data for cord angles lying between 45° and 90°. These properties were reviewed in Ref. 4, but are repeated here for convenience. They are:

$$G_{\xi\eta}(90°-\alpha) = G_{\xi\eta}(\alpha)$$

$$F_{\xi\eta}(90°-\alpha) = F_{\xi\eta}(\alpha)$$

$$E_{\xi}(45°+\alpha) = E_{\eta}(45°-\alpha)$$

$$E_{\eta}(45°+\alpha) \quad E_{\xi}(45°-\alpha)$$

Values of E_ξ/E_x are given in Table I, $F_{\xi\eta}/E_x$ in Table II, and $G_{\xi\eta}/E_x$ in Table III.

It should be noted that the modulus obtainable from an ordinary tensile test will correspond to the quantity E_ξ, if the proper value of cord angle and G_{xy}/E_x are chosen, up to a cord angle of about 56°. At this point the tensile loads applied to a specimen cause the cords to move through the zero load condition and, as the angle increases, to load the cords into compression. At this point the ratio G_{xy}/E_x changes since the effective modulus of the cord E_x changes. Thus, a new value of G_{xy}/E_x becomes applicable and, if this new value is used in reading from the tables, the resulting E_ξ will now correspond to the measured modulus on up to a cord angle of 90°.

TABLE I

DIMENSIONLESS EXTENSION MODULUS E_ξ/G_{xy}

Cord Angle (Degrees) \ G_{xy}/E_x	1×10^{-4}	5×10^{-4}	1×10^{-3}	2×10^{-3}	4×10^{-3}	6×10^{-3}	8×10^{-3}	1×10^{-2}
0	10000.00000	2000.00010	1000.00000	500.00006	250.00003	166.66668	125.00001	100.00000
1	9988.55100	1998.08340	999.06635	499.54036	249.77298	166.51655	124.88822	99.91119
2	9926.72640	1991.23840	995.99362	498.09461	249.07586	166.05935	124.54917	99.64246
3	9735.57090	1976.23750	989.98075	495.46642	247.86156	165.27505	123.97212	99.18726
4	9304.22820	1947.97440	979.74028	491.33753	246.05351	164.13104	123.13948	98.53485
5	8542.17540	1900.12740	963.60775	485.28785	243.54965	162.58366	122.02778	97.67090
6	7452.50150	1826.44750	939.74055	476.82723	240.22795	160.58051	120.60877	96.57817
7	6163.48630	1722.70900	906.44662	465.45123	235.95607	158.06382	118.85102	95.23730
8	4867.09190	1588.76730	862.60515	450.71075	230.60331	154.97485	116.72225	93.62851
9	3718.65900	1429.71250	808.08798	432.29940	224.05557	151.25901	114.19178	91.73253
10	2788.01040	1255.25350	744.06324	410.14770	216.23434	146.87332	111.23382	89.53301
11	2074.82900	1077.25070	672.94147	384.48581	207.11358	141.79241	107.83115	87.01807
12	1544.98740	906.73134	598.02607	355.86530	196.73571	136.01604	103.97833	84.18278
13	1156.77460	751.67414	522.88638	325.11920	185.21966	129.57406	99.68518	81.03074
14	873.17138	616.35554	450.73114	293.26131	172.75992	122.52961	94.97849	77.57594
15	665.27420	501.83225	383.98392	261.35713	159.61583	114.97809	89.90382	73.84353
16	511.79197	407.00669	324.11612	230.38510	146.08855	107.04378	84.52371	69.87002
17	397.47019	329.64273	271.72777	201.14411	132.49502	98.87133	78.91598	65.70233
18	311.48820	267.10094	226.74881	174.19615	119.13950	90.61560	73.16887	61.39582
19	246.18127	216.79748	188.67671	149.86555	106.28884	82.43048	67.37616	57.01171
20	196.10283	176.42211	156.77735	128.26784	94.15676	74.45807	61.63088	52.61357
21	157.34872	144.01422	130.23672	109.35821	82.89591	66.82066	56.02014	48.26410
22	127.09873	117.96397	108.25311	92.98161	72.59855	59.61478	50.62036	44.02147
23	103.29800	96.97393	90.09090	78.91840	63.30303	52.90969	45.49409	39.93701
24	84.43233	80.01072	75.10329	66.91927	55.00406	46.74741	40.68857	36.05311
25	69.37682	66.25663	62.73687	56.72976	47.66332	41.14595	36.23516	32.40215
26	57.28679	55.06627	52.52694	48.10664	41.22035	36.10312	32.15089	29.00650
27	47.52316	45.99052	44.08818	40.82641	35.60156	31.60116	28.43993	25.87894
28	39.59783	38.44740	37.10362	34.68969	30.72740	27.61116	25.09619	23.02379
29	33.13480	32.29851	31.31356	29.52192	26.51736	24.09694	22.10545	20.43816
30	27.84253	27.23113	26.50595	25.17249	22.89386	21.01843	19.44792	18.11358
31	23.49315	23.04393	22.50787	21.51291	19.78436	18.33419	17.10018	16.03738
32	19.90723	19.57574	19.17811	18.43406	17.12249	16.00319	15.03680	14.19400
33	16.94266	16.69717	16.40136	15.84392	14.84862	13.98620	13.23173	12.56615
34	14.48621	14.30387	14.08330	13.66508	12.90986	12.24653	11.65928	11.13575
35	12.44706	12.31134	12.14661	11.83255	11.25975	10.75050	10.29480	9.88463
36	10.75204	10.65089	10.52773	10.29182	9.85775	9.46764	9.11514	8.79509
37	9.34185	9.26641	9.17443	8.99719	8.66870	8.37061	8.09890	7.85023
38	8.16823	8.11198	8.04317	7.91033	7.66224	7.43516	7.22655	7.03424
39	7.19168	7.14981	7.09847	6.99905	6.81222	6.63989	6.48045	6.33251
40	6.37979	6.34869	6.31050	6.23632	6.09617	5.96600	5.84479	5.73116
41	5.70580	5.68280	5.65451	5.59941	5.49481	5.39705	5.30551	5.21962
42	5.14759	5.13067	5.10983	5.06916	4.99160	4.91873	4.85014	4.78548
43	4.68676	4.67441	4.65918	4.62940	4.57239	4.51858	4.46770	4.41952
44	4.30797	4.29905	4.28804	4.26647	4.22505	4.18578	4.14851	4.11310

TABLE I (Concluded)

DIMENSIONLESS EXTENSION MODULUS E_ξ/G_{xy}

Cord Angle (Degrees) \ G_{xy}/E_x	1×10^{-4}	5×10^{-4}	1×10^{-3}	2×10^{-3}	4×10^{-3}	6×10^{-3}	8×10^{-3}	1×10^{-2}
45	3.99840	3.99205	3.98421	3.96881	3.93917	3.91097	3.88412	3.85852
46	3.74730	3.74287	3.73739	3.72662	3.70585	3.68603	3.66711	3.64902
47	3.54561	3.54261	3.53889	3.53157	3.51744	3.50393	3.49100	3.47863
48	3.38572	3.38376	3.38134	3.37658	3.36738	3.35858	3.35016	3.34209
49	3.26115	3.25996	3.25850	3.25561	3.25005	3.24473	3.23965	3.23480
50	3.16645	3.16582	3.16504	3.16352	3.16059	3.15782	3.15519	3.15271
51	3.09697	3.09674	3.09645	3.09590	3.09486	3.09392	3.09305	3.09228
52	3.04877	3.04881	3.04887	3.04899	3.04927	3.04960	3.04998	3.05041
53	3.01847	3.01870	3.01898	3.01956	3.02073	3.02193	3.02316	3.02441
54	3.00319	3.00354	3.00397	3.00484	3.00658	3.00834	3.01012	3.01190
55	3.00048	3.00090	3.00141	3.00245	3.00453	3.00662	3.00872	3.01082
56	3.00823	3.00867	3.00923	3.01036	3.01260	3.01485	3.01710	3.01936
57	3.02462	3.02508	3.02565	3.02679	3.02907	3.03136	3.03365	3.03594
58	3.04811	3.04855	3.04911	3.05023	3.05246	3.05471	3.05695	3.05920
59	3.07735	3.07778	3.07831	3.07937	3.08150	3.08364	3.08579	3.08794
60	3.11121	3.11161	3.11210	3.11309	3.11508	3.11708	3.11908	3.12109
61	3.14869	3.14905	3.14950	3.15041	3.15223	3.15407	3.15591	3.15776
62	3.18893	3.18926	3.18967	3.19049	3.19214	3.19380	3.19547	3.19715
63	3.23121	3.23150	3.23187	3.23260	3.23407	3.23555	3.23705	3.23856
64	3.27489	3.27514	3.27546	3.27611	3.27741	3.27872	3.28004	3.28138
65	3.31941	3.31963	3.31991	3.32047	3.32161	3.32276	3.32392	3.32510
66	3.36431	3.36450	3.36475	3.36523	3.36621	3.36721	3.36822	3.36924
67	3.40918	3.40935	3.40955	3.40997	3.41081	3.41166	3.41253	3.41341
68	3.45367	3.45381	3.45398	3.45434	3.45505	3.45577	3.45651	3.45727
69	3.49747	3.49759	3.49773	3.49803	3.49863	3.49924	3.49986	3.50050
70	3.54033	3.54042	3.54054	3.54079	3.54128	3.54179	3.54231	3.54285
71	3.58200	3.58208	3.58218	3.58238	3.58279	2.58321	3.58364	3.58408
72	3.62231	3.62237	3.62245	3.62261	3.62294	3.62329	3.62364	3.62400
73	3.66108	3.66113	3.66119	3.66132	3.66159	3.66186	3.66215	3.66244
74	3.69816	3.69820	3.69825	3.69835	2.69856	3.69878	3.69901	3.69925
75	3.73344	3.73347	3.73351	3.73359	3.73375	3.73393	3.73411	3.73430
76	3.76681	3.76683	3.76686	3.76692	3.76705	3.76718	3.76732	3.76747
77	3.79817	3.79819	3.79821	3.79825	3.79835	3.79845	3.79856	3.79867
78	3.82745	3.82746	3.82748	3.82751	3.82758	3.82766	3.82774	3.82782
79	3.85458	3.85459	3.85460	3.85462	3.85467	3.85473	3.85479	3.85485
80	3.87950	3.87951	3.87952	3.87953	3.87957	3.97961	3.87965	3.87970
81	3.90218	3.90218	3.90219	3.90220	3.90222	3.90225	3.90228	3.90231
82	3.92256	3.92256	3.92256	3.92257	3.92258	3.92260	3.92262	3.92265
83	3.94061	3.94061	3.94061	3.94061	3.94062	3.94064	3.94065	3.94067
84	3.95630	3.95630	3.95630	3.95631	3.95631	3.95632	3.95633	3.95634
85	3.96962	3.96962	3.96962	3.96962	3.96962	3.96963	3.96963	3.96964
86	3.98054	3.98054	3.98054	3.98054	3.98054	3.98054	3.98055	3.98055
87	3.98904	3.98904	3.98904	3.98905	3.98905	3.98905	3.98905	3.98905
88	3.99513	3.99513	3.99513	3.99513	3.99513	3.99513	3.99513	3.99513
89	3.99878	3.99878	3.99878	3.99878	3.99878	3.99878	3.99878	3.99878
90	4.00000	4.00000	4.00000	4.00000	4.00000	4.00000	4.00000	4.00000

TABLE II

DIMENSIONLESS EXTENSION MODULUS $F_{\xi\eta}/G_{xy}$

Cord Angle (Degrees) \ G_{xy}/E_x	1×10^{-4}	5×10^{-4}	1×10^{-3}	2×10^{-3}	4×10^{-3}	6×10^{-3}	8×10^{-3}	1×10^{-2}
0	20000.00100	4000.00030	2000.00010	1000.00010	500.00005	333.33336	250.00002	200.00001
1	7923.40910	3064.95620	1735.07380	928.94189	481.51305	324.98417	245.25724	196.94254
2	2814.54060	1800.05080	1240.93980	765.44054	433.34912	302.22895	232.02599	188.29040
3	1353.79120	1064.72570	840.41826	591.28888	371.21662	270.53329	212.81602	175.39799
4	782.06946	675.84984	577.76360	447.79282	308.85029	235.71924	190.59465	159.97389
5	505.41100	458.69939	411.19633	340.64636	253.62751	202.02846	167.88048	143.61106
6	351.77019	328.41894	303.25698	262.96644	207.76940	171.73223	146.35422	127.51547
7	257.96189	245.13384	230.78905	206.61142	170.82894	145.61889	126.89873	112.44819
8	196.60442	189.03436	180.35480	165.18821	141.41317	123.62835	109.82315	98.79625
9	154.32606	149.60243	144.09032	134.20320	118.01494	105.31875	95.09471	86.68480
10	123.98290	120.90151	117.25933	110.59767	99.31935	90.13486	82.51065	76.08026
11	101.48205	99.39821	96.91128	92.29453	84.27109	77.53696	71.80449	66.86564
12	84.34389	82.89230	81.14702	77.86941	72.05374	67.05172	62.70376	58.88944
13	70.99596	69.95957	68.70625	66.33081	62.04496	58.28416	54.95748	51.99386
14	60.40223	59.64684	58.72909	56.97682	53.77195	50.91278	48.34620	46.02952
15	51.85799	51.29778	50.61459	49.30228	46.87500	44.67942	42.68388	40.86223
16	44.87043	44.44883	43.93309	42.93748	41.07866	39.37763	37.81513	36.37488
17	39.08661	38.76539	38.37142	37.60774	36.17065	34.84254	33.61145	32.46712
18	34.24842	34.00114	33.69721	33.10598	31.98596	30.94211	29.96692	29.05382
19	30.16360	29.97162	29.73523	29.27401	28.39527	27.57032	26.79439	26.06320
20	26.68662	26.53656	26.35149	25.98949	25.29636	24.64157	24.02201	23.43492
21	23.70568	23.58778	23.44217	23.15672	22.60783	22.08645	21.59054	21.11829
22	21.13378	21.04081	20.92586	20.70007	20.26428	19.84832	19.45087	19.07071
23	18.90240	18.82896	18.73805	18.55918	18.21280	17.88077	17.56221	17.25632
24	16.95705	16.89902	16.82712	16.68545	16.41028	16.14551	15.89056	15.64488
25	15.25391	15.20814	15.15140	15.03943	14.82138	14.61085	14.40745	14.21083
26	13.75749	13.72155	13.67696	13.58887	13.41691	13.25037	13.08898	12.93251
27	12.43879	12.41078	12.37600	12.30722	12.17266	12.04197	11.91496	11.79150
28	11.27398	11.25240	11.22558	11.17250	11.06844	10.96710	10.86836	10.77212
29	10.24329	10.22695	10.20664	10.16638	10.08731	10.01009	9.93467	9.86098
30	9.33031	9.31826	9.30327	9.27354	9.21501	9.15771	9.10159	9.04661
31	8.52130	8.51278	8.50217	8.48109	8.43952	8.39869	8.35859	8.31919
32	7.80472	7.79910	7.79210	7.77818	7.75062	7.72346	7.69669	7.67028
33	7.17085	7.16763	7.16361	7.15560	7.13968	7.12388	7.10820	7.09264
34	6.61149	6.61025	6.60870	6.60559	6.59931	6.59296	6.58653	6.58003
35	6.11969	6.12010	6.12060	6.12154	6.12327	6.12477	6.12605	6.12712
36	5.68961	5.69137	5.69356	5.69787	5.70622	5.71424	5.72194	5.72931
37	5.31629	5.31917	5.32275	5.32983	5.34367	5.35708	5.37009	5.38270
38	4.99559	4.99939	5.00411	5.01346	5.03179	5.04965	5.06703	5.08396
39	4.72402	4.72857	4.73422	4.74542	4.76741	4.78888	4.80983	4.83028
40	4.49875	4.50389	4.51028	4.52295	4.54788	4.57224	4.59606	4.61935
41	4.31743	4.32304	4.33001	4.34384	4.37105	4.39768	4.42374	4.44925
42	4.17824	4.18419	4.19160	4.20629	4.23522	4.26355	4.29130	4.31847
43	4.07979	4.08598	4.09369	4.10898	4.13910	4.16861	4.19753	4.22586
44	4.02110	4.02743	4.03532	4.05096	4.08178	4.11199	4.14160	4.17061
45	4.00160	4.00798	4.01592	4.03168	4.06274	4.09318	4.12301	4.15225

TABLE III

DIMENSIONLESS SHEAR MODULUS $G_{\xi\eta}/G_{xy}$

Cord Angle (Degrees) \ G_{xy}/E_x	1×10^{-4}	5×10^{-4}	1×10^{-3}	2×10^{-3}	4×10^{-3}	6×10^{-3}	8×10^{-3}	1×10^{-2}
0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1	4.04403	1.60807	1.30358	1.15133	1.07521	1.04984	1.03715	1.02954
2	13.16128	3.42934	2.21284	1.60460	1.30048	1.19911	1.14842	1.11801
3	28.30736	6.45491	3.72336	2.35759	1.67470	1.44708	1.33327	1.26499
4	49.40829	10.67006	5.82777	3.40663	2.19607	1.79255	1.59080	1.46975
5	76.36158	16.05425	8.51582	4.74662	2.86202	2.23384	1.91975	1.73130
6	109.03508	22.58115	11.77439	6.37100	3.66933	2.76878	2.31852	2.04837
7	147.26868	30.21905	15.58764	8.27190	4.61405	3.39478	2.78517	2.41941
8	190.87539	38.93080	19.93703	10.44005	5.69159	4.10880	3.31742	2.84261
9	239.64838	48.67381	24.80118	12.86485	6.89670	4.90734	3.91269	3.31591
10	293.35750	59.40084	30.15667	15.53452	8.22350	5.78652	4.56806	3.83701
11	351.71513	71.05932	35.97715	18.43605	9.66553	6.74205	5.28035	4.40336
12	414.44077	83.59296	42.23440	21.55531	11.21576	7.76929	6.04609	5.01221
13	481.25742	96.93924	48.89803	24.87708	12.86664	8.86321	6.86155	5.66059
14	551.82156	111.03597	55.93536	28.38515	14.61012	10.01851	7.72275	6.34534
15	625.79789	125.81243	63.31242	32.06262	16.43774	11.22953	8.62550	7.06313
16	702.79501	141.19447	70.99283	35.89124	18.34056	12.49040	9.56540	7.81045
17	782.47873	157.11215	78.93950	39.85266	20.30931	13.79496	10.53788	8.58368
18	864.47608	173.48461	87.11340	43.92739	22.33444	15.13687	11.53818	9.37904
19	948.23580	190.23233	95.47533	48.09575	24.40603	16.50958	12.56146	10.19265
20	1033.58100	207.27751	103.98372	52.33725	26.51403	17.90639	13.60271	11.02055
21	1120.09670	224.53039	112.59841	56.63139	28.64816	19.32054	14.65686	11.85873
22	1207.01510	241.91285	121.27665	60.95710	30.79800	20.74507	15.71876	12.70307
23	1294.28050	259.33744	129.97512	65.29337	32.95302	22.17311	16.78324	13.54947
24	1381.15820	276.71626	138.65202	69.61917	35.10287	23.59766	17.84518	14.39381
25	1467.67440	293.97239	147.26607	73.91316	37.23703	25.01177	18.89931	15.23197
26	1552.96380	311.01393	155.77488	78.15492	39.34500	26.40859	19.94057	16.05987
27	1636.79510	327.76246	164.13650	82.32309	41.41653	27.78130	20.96383	16.87348
28	1718.89230	344.13693	172.30981	86.39764	43.44169	29.12320	21.96414	17.66884
29	1798.49640	360.05285	180.25780	90.35946	43.41046	30.42774	22.93663	18.44208
30	1875.18750	375.42892	187.93601	94.18723	47.31311	31.68857	23.87648	19.18938
31	1949.39370	390.21040	195.31440	97.86526	49.14087	32.89966	24.77925	19.90718
32	2019.95710	404.30994	202.35214	101.37340	50.88440	34.05495	25.64046	20.59193
33	2086.59360	417.65511	209.01480	104.69493	52.53516	35.14889	26.45592	21.24030
34	2149.47440	430.18153	215.27088	107.81427	54.08534	36.17611	27.22165	21.84916
35	2207.70040	441.84443	221.09170	110.71573	55.52751	37.13165	27.93395	22.41550
36	2261.42010	452.57674	226.44722	113.38536	56.85426	38.01083	28.58933	22.93662
37	2310.37580	462.30802	231.31281	115.81017	58.05933	38.80936	29.18458	23.40990
38	2353.93810	471.02934	235.66119	117.97836	59.13696	39.52336	29.71684	23.83311
39	2392.05830	478.66357	239.47507	119.87935	60.08160	40.14939	30.18349	24.20414
40	2424.77140	485.19194	242.73435	121.50402	60.88899	40.68441	30.58230	24.52121
41	2451.88180	490.57844	245.42226	122.84393	61.55490	41.12568	30.91121	24.78278
42	2472.73800	494.79475	247.52659	123.89286	62.07641	41.47111	31.16875	24.98752
43	2488.11920	497.81459	249.03622	124.64584	62.45047	41.71908	31.35357	25.13451
44	2497.06590	499.63526	249.94376	125.09898	62.67577	41.86831	31.46485	25.22300
45	2500.12500	500.24762	250.24899	125.25018	62.75093	41.91814	31.50200	25.25251

IV. REFERENCES

1. S. K. Clark, Interply Shear Stresses in Cord Rubber Laminates, The University of Michigan, ORA Technical Report 02957-4-T, Ann Arbor, Michigan, October 1960.

2. S. K. Clark, R. N. Dodge, N. L. Field, and B. Herzog, Digital Computation of Two-Ply Elastic Characteristics, The University of Michigan, ORA Technical Report 02957-12-T, Ann Arbor, Michigan, October 1961.

3. S. K. Clark, The Elastic Constants of Cord-Rubber Laminates, The University of Michigan, ORA Technical Report 02957-6-T, Ann Arbor, Michigan, October 1960.

4. S. K. Clark, The Plane Elastic Characteristics of Cord-Rubber Laminates, The University of Michigan, ORA Technical Report 02957-3-T, Ann Arbor, Michigan, October 1960.

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