Quality Assurance Measurements
on
20 As-manufactured Brake Pads

Summary

This report describes the results obtained from ultrasonic measurements using the ETEK on 20 intact automotive brake pads. For each pad, we measured 8 different positions in the "out-of-plane" (through-the-thickness) direction and 4 different positions propagating in-the-plane of the pad. For each of these positions we measured both the longitudinal and shear propagation speeds. All data was corrected for the presence of the steel backing so that the data is representative of only the friction material. Graphic presentation of the data is given in this report. Tabular data is included in the Appendix A. In Table S-I we summarize the mean measured values for each mode. The "Group" % deviations indicate the Pad-to Pad variations for this material type while the "Pad" % deviations refer to the average measurement variation within each pad. In each case, the pad-to-pad variations are less than the variations within individual pads.

Table S-I Comparison of Group and Individual Pad Deviations (n=20)

			Avg	Min	Max
Mode	Group	Group	Pad	Pad	Pad
	AVG (Km/sec)	% Dev	% Dev	% Dev	% Dev
V_{32}	1.069	2.52	5.27	2.74	7.27
V_{33}	1.261	3.20	6.28	3.74	8.70
V_{21}	1.512	2.03	5.59	1.25	9.68
V_{22}	2.303	2.66	4.98	1.77	10.42

For selected pads, and measurement positions, the load-dependence of the measured velocity was also measured. This measurement quantifies the non-linear performance of the materials. These pads exhibited moderate load-dependence in the out-of-plane modes with the modulus increasing 10 to 20 percent for loads from 0.5 MPa to 7.5 MPa.

For completeness, we analyzed one of the samples destructively using the conventional ultrasonic analysis methodology (SAE J2725 specification) to extract the complete set of elastic constants. These results are presented in Appendix C for the test sample, the pad, and the entire group of 20 pads. The results for the entire group are reproduced below.

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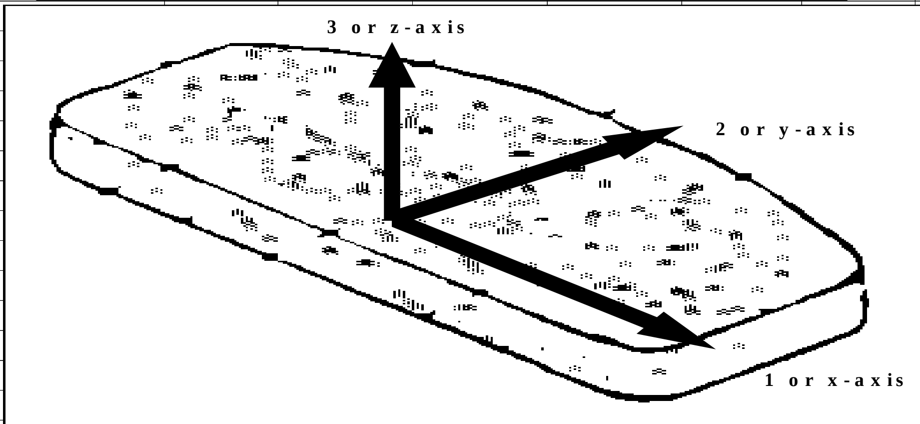
Group Average 20 Brake Pads

Disc Pad Coordinate Definition



Ultrasound Velocity

V33 Km/sec	<V22;V11> Km/sec	<V31,V32> Km/sec	V12 Km/sec	Rho Gm/cc	V45 km/sec
1.261	2.303	1.069	1.512	2.661	0.973

Elastic Constants

C11 Gpa	C22 Gpa	C33 Gpa	C44 Gpa	C55 Gpa	C66 Gpa	C12 Gpa	C13 Gpa
14.11	14.11	4.23	3.04	3.04	6.08	1.95	2.16

Engineering Constants

	Gpa	Ksi	
Ex=Ey	12.95	1877.8	Young' Modulus(in-Plane)
v12=v21	0.06	0.06	Poisson's Ratio
Ez=E3	3.65	528.9	Young's Modulus (out-of Plane)
v31=v32	0.13	0.13	Poisson's Ratio
v23=v13	0.48	0.48	Poisson's Ratio
G13=G23	3.04	440.9	Shear Modulus(in-Plane)
G12	6.08	882.0	Shear Modulus (out-of-Plane)

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Ultrasonic Velocity Data on 20 Brake Pads

Documentation

For each pad we measured 8 different positions in the "through-the thickness" direction and 4 different positions propagating in-the-plane of the pad. For each of these positions we measure both the longitudinal and shear propagation speeds. All data has been corrected for the presence of the steel backing so that the data is representative of only the friction material. The location of the various measurement points is shown in Figure 1.

Out-of-plane velocity modes are related (sometimes in mysterious ways) to the compressibility. The in-plane velocity measurements are related the in-plane modulus and thus control the bending pad vibration modes. The relationship between the velocity and the relevant elastic constant is given below: For the presentation of the data we use the measured ultrasonic velocity.

$C_{33} = \rho*(V_{33})^2$ $C_{44} = \rho*(V_{32})^2$ out-of-plane

$C_{22} = \rho*(V_{22})^2$ $C_{66} = \rho*(V_{21})^2$ in-plane

With the velocity in units of (Km/sec) and the density in (g/cc) the product yields modulus in GPa. In this work only the velocity is measured locally. The measurements for all 4 modes are presented in 2 different ways. In one plot the average velocity value for each pad is presented along with the standard deviation within the pad. This presentation format allows one to visually compare the pad-to-pad variation (difference between #1 and #20) with the variation within each pad (error bar on each point). The second format involves computing the average and standard deviation of the measured velocity at each position for all 20 pads.

Figure 2 shows the average out-of-plane data for the shear velocity (2a) and the longitudinal velocity (2b) for all 20 brake pads. The standard deviation on each point quantifies the measured variation within each pad (n=8) while the variation for pads 1 to 20 shows the pad-to-pad variation. Data in this Figure suggests a general correlation between the shear and longitudinal measurements. The variation within the individual pads is typically larger than the pad-to-pad variations and is summarized in Table I. Additionally, the standard deviation of the shear wave measurements is slightly less than that observed with the longitudinal measurements. The features that stand out in Figure 2 are the low values for pads #4 and #5 for both the shear and longitudinal waves and the small standard deviations in pad #10.

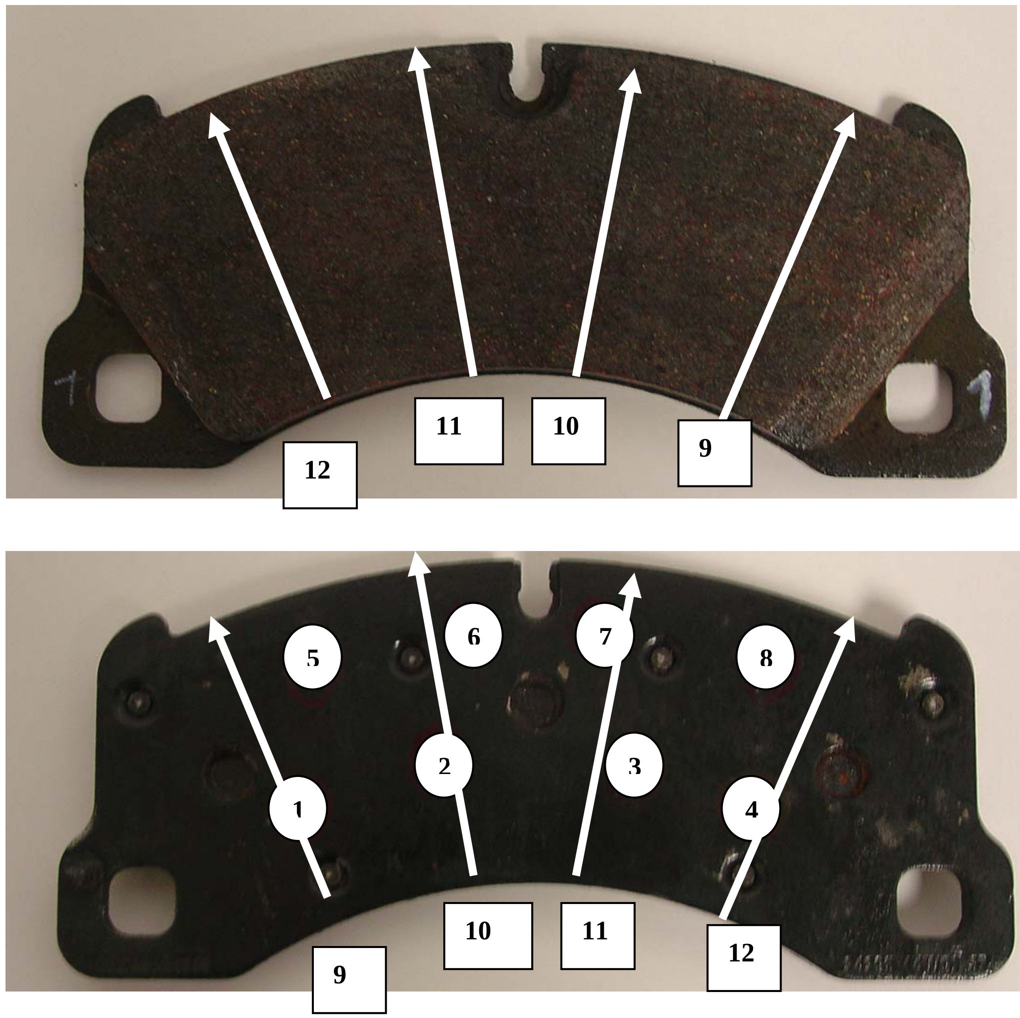
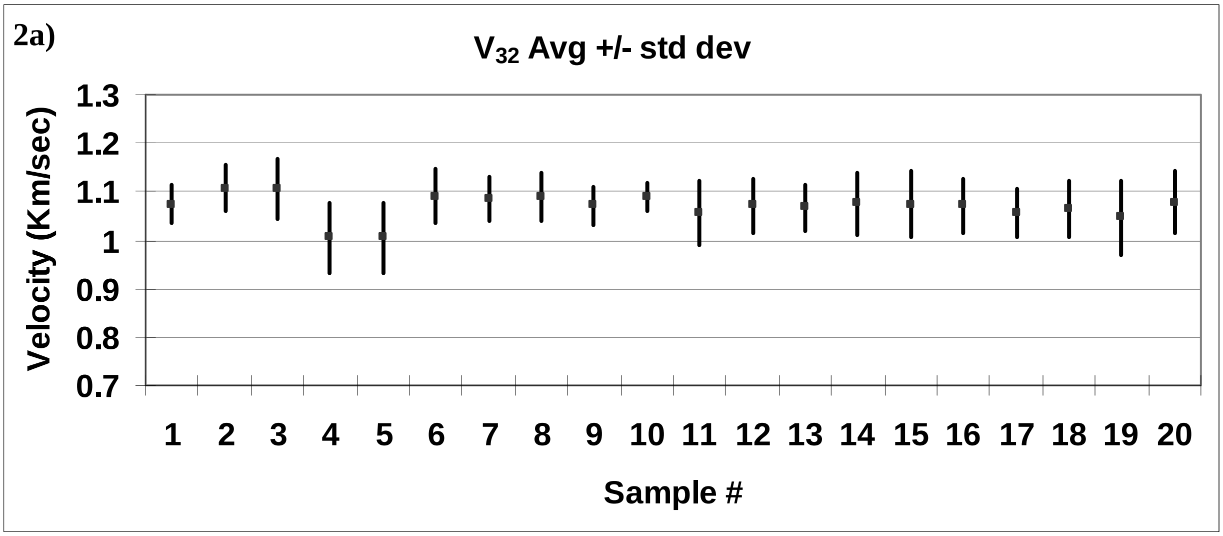


Figure 1 Location of measurement positions in brake pads. The "footprint" of the sensor is approximately 1 centimeter in diameter. The arrows show the propagation path for the in-plane modes V_{21} and V_{22}, while the circles show the transducer "footprint" for the out-of-plane modes V_{33}, and V_{32}. In this case the propagation in perpendicular to the plane of the page.

Ultrasonic velocity measurements on all 20 Brake Pads (Out-of-plane modes).



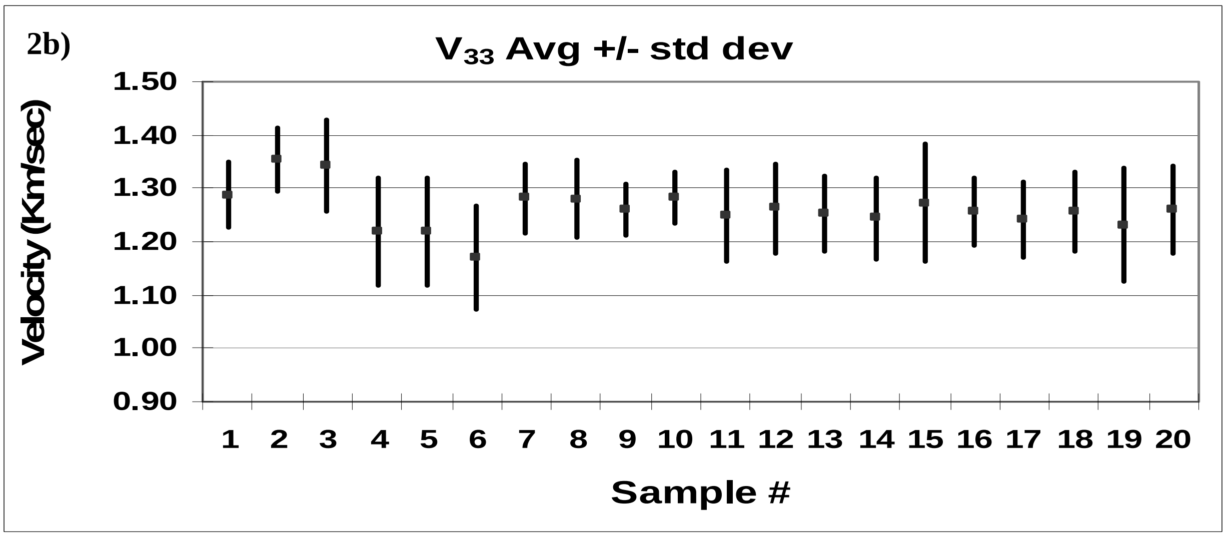


Figure 2 a) Mean V_{32} shear velocity and standard deviation of 8 measurements made on all 20 brake pads. b) Mean V_{33} longitudinalvelocity (n=8) and standard deviation of all 20 brake pads.

Table I Comparison of Group and Individual Pad Deviations

			Avg	Min	Max
Mode	Group	Group	Pad	Pad	Pad
	AVG (Km/sec)	% Dev	% Dev	% Dev	% Dev
V_{32}	1.069	2.52	5.27	2.74	7.27
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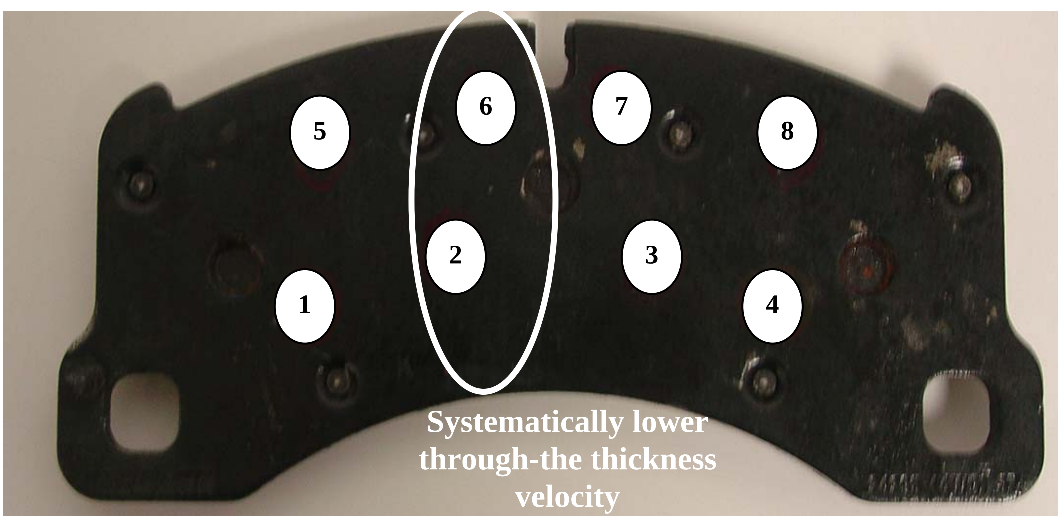
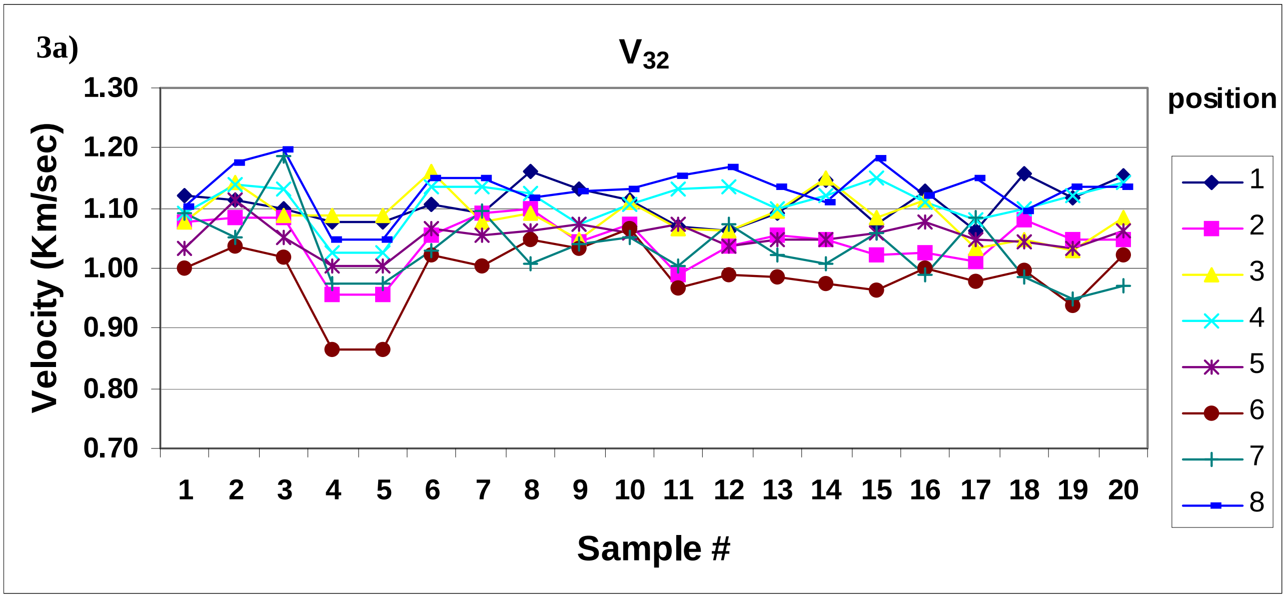
Figure 3 shows the same data presented in Figure 2. However, in this case, we have averaged the data by position. The value of this presentation format is to determine if there are systematic spatial variations in the pad velocity measurements. This might indicate specific processing variations. The primary feature apparent in Figure 3 is that position 2 and position 6 exhibit significantly slower shear and longitudinal velocity. The figure below shows the location of the two positions.





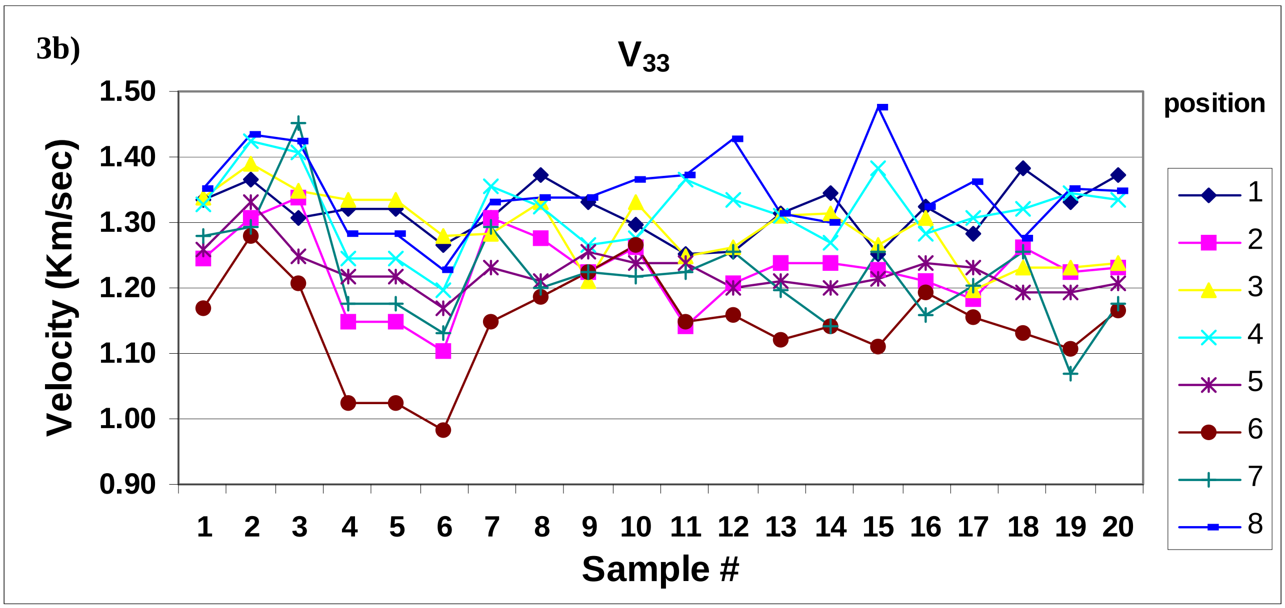
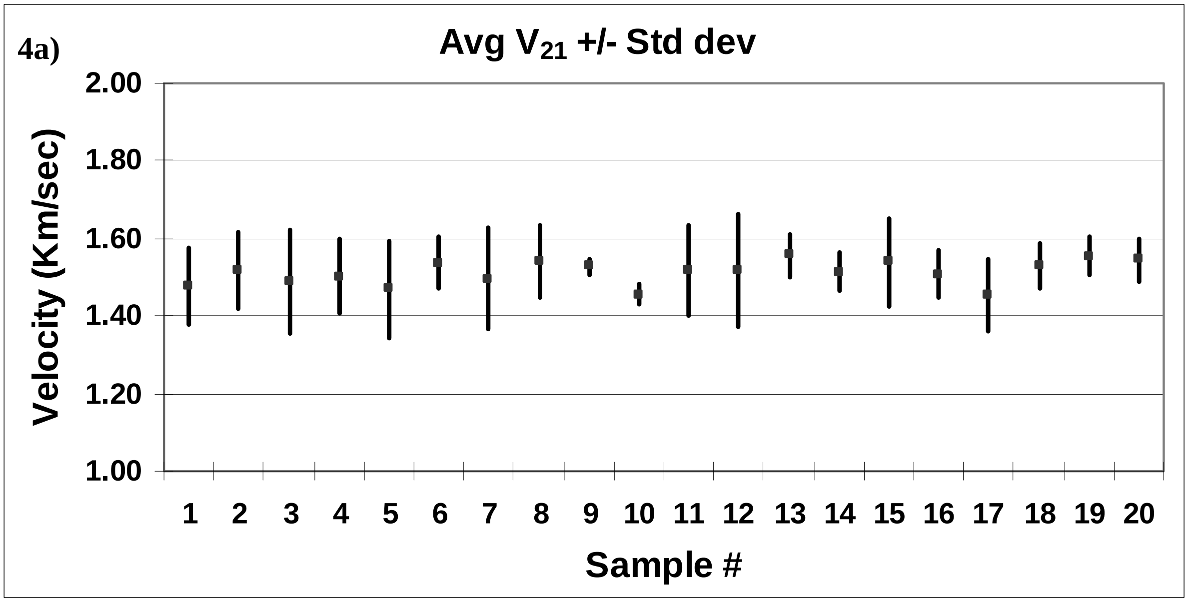


Figure 3 a) Out-of-plane shear velocity, V_{32}, measured on 8 positions of the 20 brake pads. b) Out-of plane longitudinal velocity, V_{33}, measured on 8 positions of the 20 brake pads. (see Figure 1 for locations)



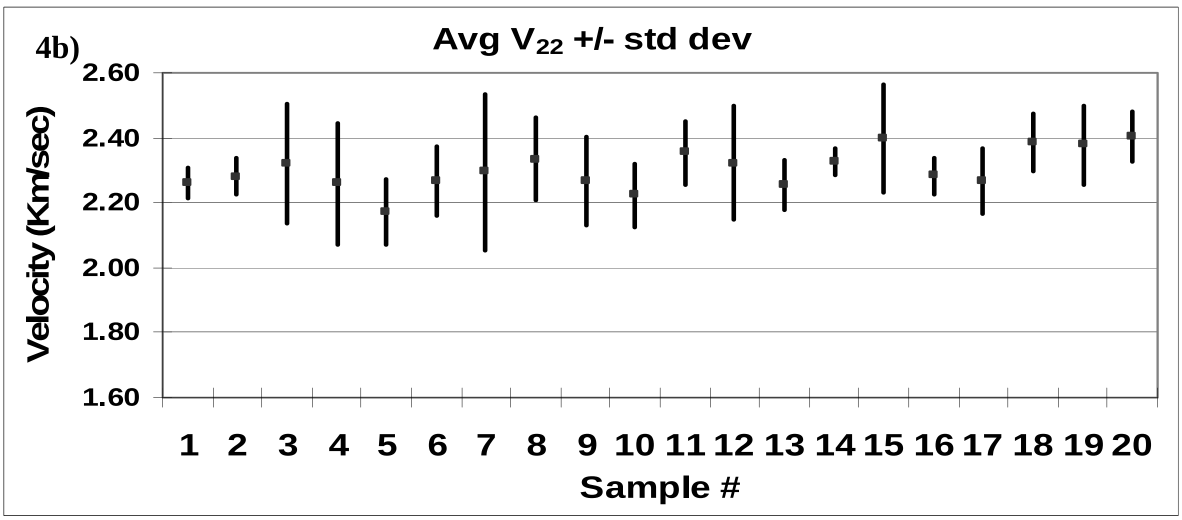


Figure 4 a) Mean V_{21} shear velocity and standard deviation of 4 measurements made on all 20 pads. b) Mean V_{22} longitudinal velocity and standard deviation of all pads.

Unlike the out-of-plane modes, this data shows no obvious features that distinguish one pad from another. Deviations are larger for the longitudinal waves. Pad #4 and #5 are not differentiated, although pad #10, like the out-of-plane modes shows the better uniformity.

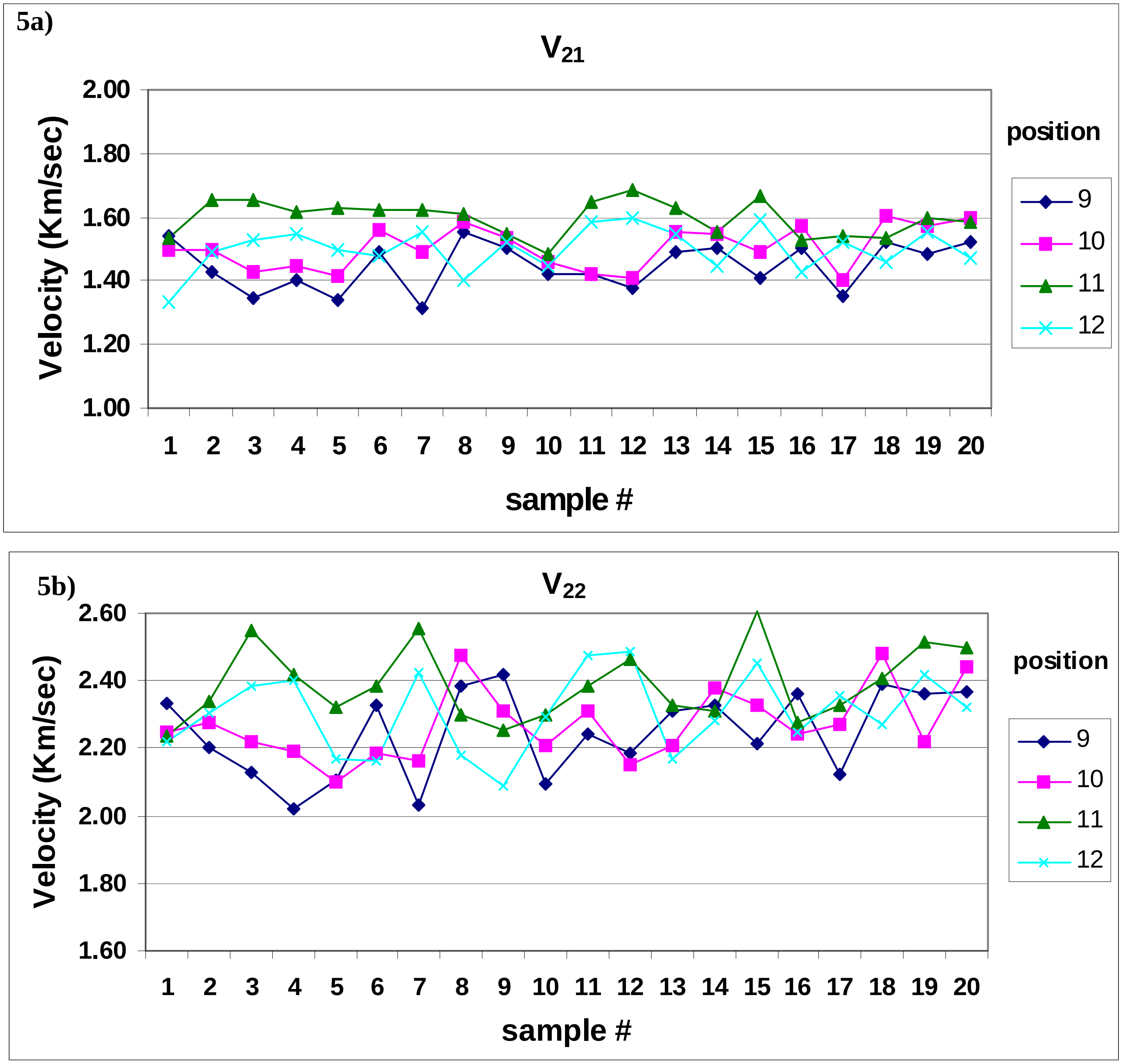


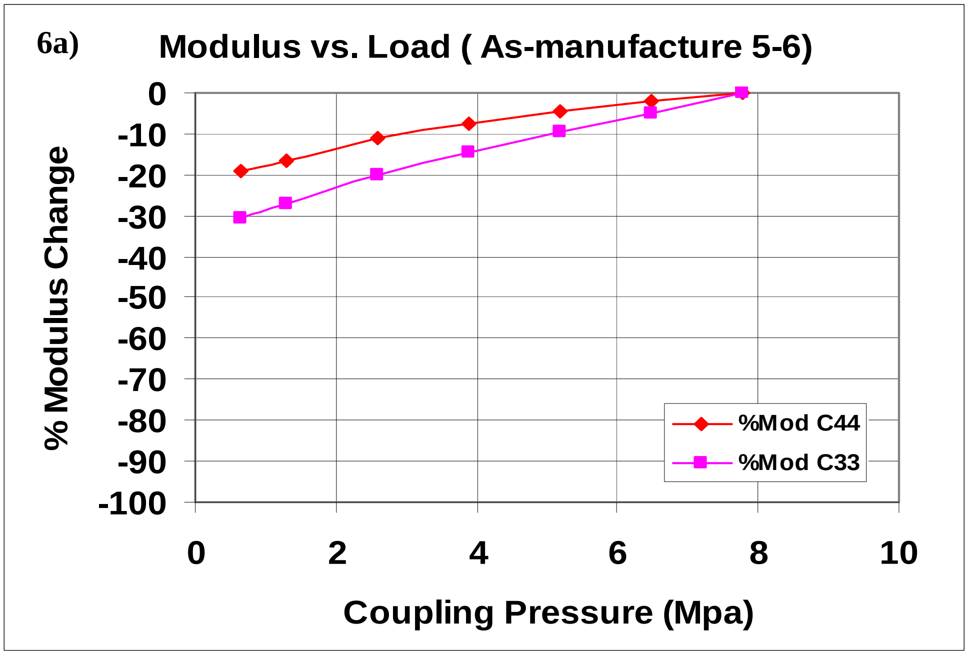
Figure 5 a) In-plane shear velocity, V_{21}, measured on 4 positions of the 20 brake pads. b) In-plane longitudinal velocity, V_{22}, measured on 4 positions of the 20 brake pads.

In-plane measurement modes plotted as a function of position show no differentiation among the 20 pads. There appears to be no systematic spatial variation.

Load Dependence

Our experience with friction materials indicates that reliable/reproducible measurements of the out-of-plane modes require measuring the ultrasonic velocity at a specific coupling load. This arises due to non-linear properties of the friction material. The results presented in the previous section were generated using a coupling force of 250 pounds which results in a coupling pressure of ~5 MPa for the V_{33} and V_{32} modes. In contrast to the though-the-thickness modes, the in-plane modes are not load dependent. In order to provide the reader with some background in Appendix B we present typical load dependent data obtained on 7 different friction materials. These results show that some friction materials exhibit little or no variation in modulus (proportional to the square of the velocity) with load (0.5 MPa to 7.5 MPa) while in other materials, the modulus can vary by as much as 50% for V_{33} and V_{32}.

Figure 6 shows load-dependent measurements on the two different positions of pad 5. Position 6 exhibited unusually low ultrasonic velocity in the out-of-plane direction and appears to have a stronger load dependence relative to position 3. Figure 7 shows similar measurements made on pad number 10. This particular pad showed unusually small velocity variations. This also appears to have less dependence on coupling pressure. Although this measurement is relatively straight-forward, it has not been automated at this point. Thus, only a few pad positions were measured.



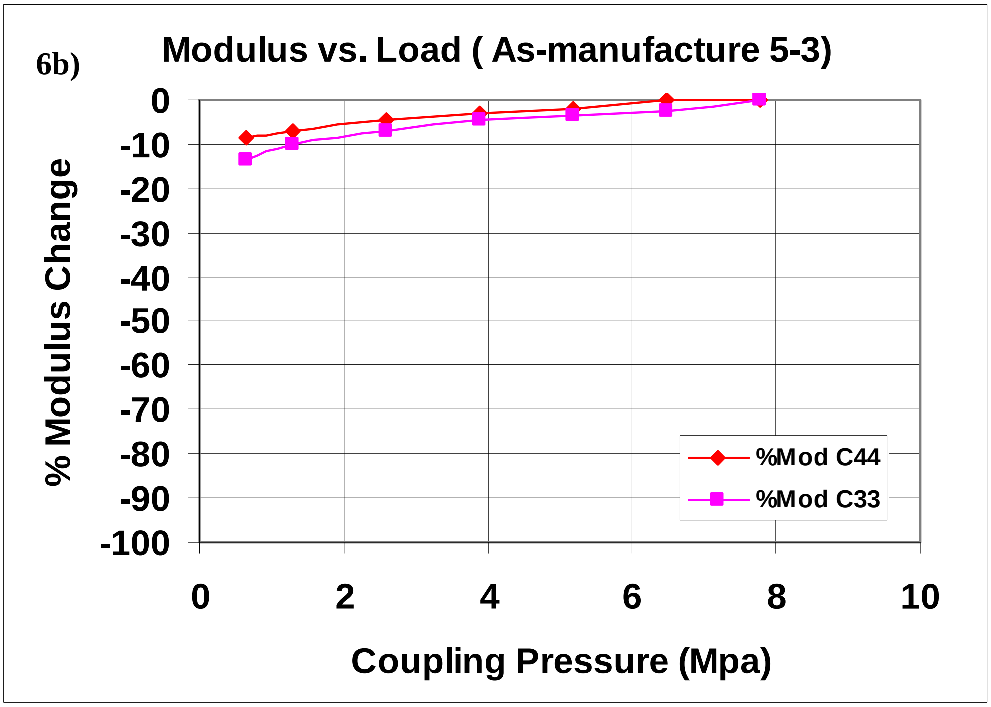


Figure 6 Longitudinal Modulus (C_{33}) and Shear Modulus (C_{44}) as a function of coupling pressure for pad 5 position 6 and pad 5 position 3.

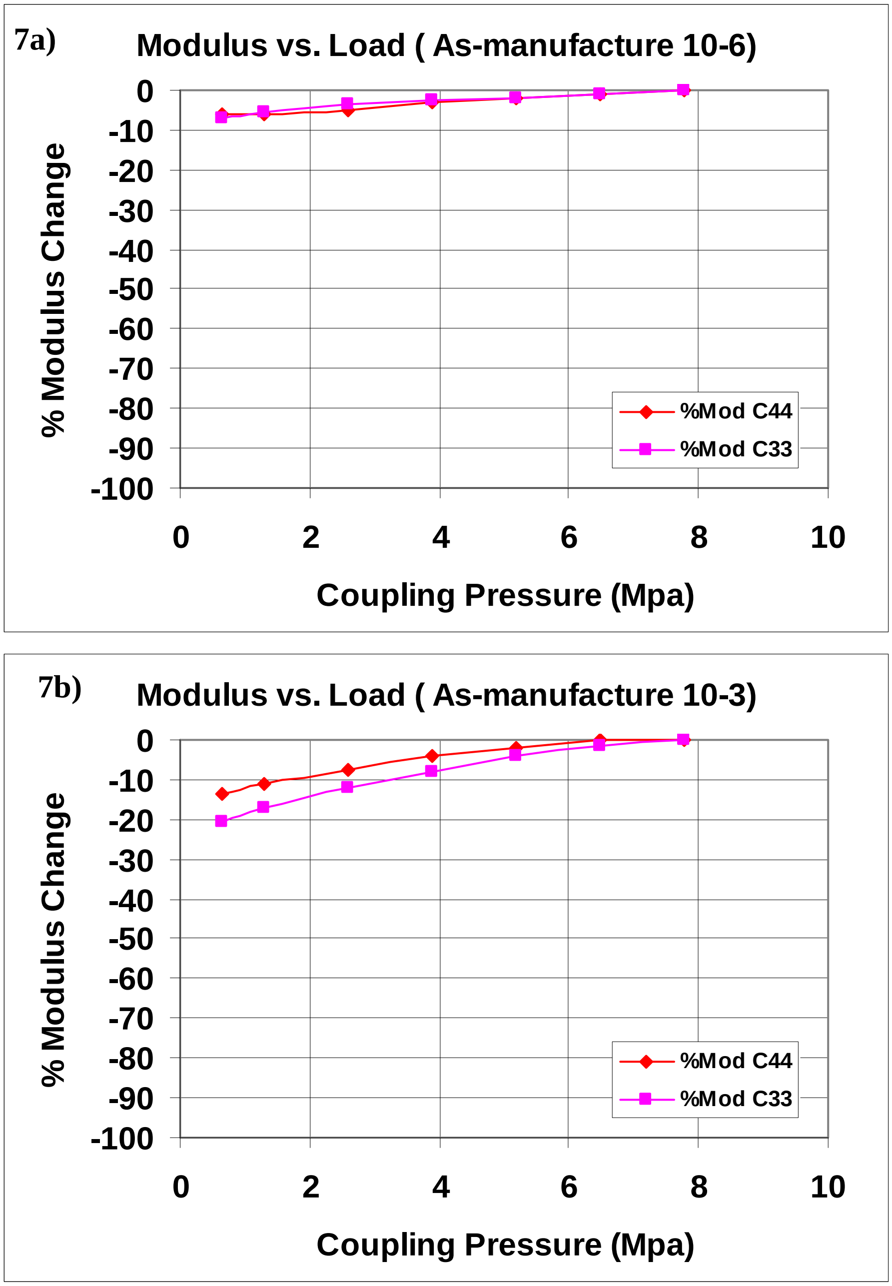


Figure 7   Longitudinal Modulus (C_{33}) and Shear Modulus (C_{44}) as a function of coupling pressure for pad 10 position 6 and pad 10 position 3.

APPENDIX A

RAW DATA

AS_MANUFACTURED PADS

All velocity numbers are in units of Km/sec

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Table I Out-of-plane V_{32}, Shear Mode Measurements

V_{32}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pos 1	1.120	1.115	1.098	1.075	1.075	1.105	1.091	1.161	1.131	1.113	1.069	1.064	1.091	1.146	1.074	1.128	1.064	1.158	1.116	1.155
pos 2	1.075	1.082	1.082	0.956	0.956	1.053	1.091	1.099	1.043	1.074	0.988	1.038	1.053	1.046	1.023	1.026	1.012	1.080	1.048	1.048
pos 3	1.075	1.143	1.088	1.086	1.086	1.161	1.077	1.091	1.048	1.110	1.066	1.061	1.096	1.149	1.085	1.113	1.033	1.046	1.031	1.085
pos 4	1.092	1.138	1.132	1.024	1.024	1.137	1.134	1.125	1.074	1.108	1.131	1.134	1.099	1.119	1.149	1.110	1.080	1.099	1.119	1.143
pos 5	1.034	1.115	1.052	1.005	1.005	1.066	1.053	1.061	1.072	1.059	1.074	1.036	1.048	1.048	1.059	1.077	1.046	1.043	1.033	1.064
pos 6	1.001	1.037	1.018	0.864	0.864	1.023	1.002	1.048	1.033	1.066	0.968	0.991	0.986	0.973	0.962	1.000	0.979	0.995	0.937	1.021
pos 7	1.092	1.052	1.186	0.976	0.976	1.028	1.096	1.009	1.041	1.051	1.004	1.074	1.023	1.007	1.059	0.988	1.085	0.986	0.947	0.971
pos 8	1.103	1.177	1.199	1.049	1.049	1.149	1.149	1.116	1.128	1.131	1.155	1.167	1.137	1.110	1.183	1.122	1.149	1.096	1.137	1.137
avg	1.074	1.107	1.107	1.005	1.005	1.090	1.087	1.089	1.071	1.089	1.057	1.071	1.067	1.075	1.074	1.071	1.056	1.063	1.046	1.078
std dev	0.039	0.047	0.062	0.073	0.073	0.055	0.046	0.048	0.039	0.030	0.066	0.056	0.048	0.066	0.069	0.057	0.051	0.057	0.076	0.065
avg+std	1.113	1.155	1.169	1.077	1.077	1.145	1.132	1.137	1.110	1.119	1.124	1.127	1.115	1.140	1.143	1.128	1.107	1.120	1.122	1.143
avg-std	1.035	1.060	1.044	0.932	0.932	1.036	1.041	1.041	1.033	1.059	0.991	1.014	1.019	1.009	1.005	1.013	1.004	1.006	0.970	1.013
std %	3.61	4.29	5.64	7.22	7.22	5.02	4.19	4.41	3.60	2.74	6.28	5.25	4.52	6.12	6.42	5.37	4.88	5.38	7.27	6.02

Table II Out-of-plane V_{33}, Longitudinal Mode Measurements

V_{33}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pos 1	1.335	1.364	1.308	1.319	1.319	1.265	1.307	1.374	1.331	1.295	1.250	1.254	1.315	1.344	1.250	1.323	1.284	1.382	1.331	1.374
pos 2	1.246	1.308	1.339	1.149	1.149	1.103	1.307	1.276	1.226	1.261	1.141	1.208	1.240	1.240	1.229	1.212	1.182	1.261	1.226	1.232
pos 3	1.336	1.389	1.347	1.335	1.335	1.280	1.284	1.331	1.212	1.331	1.247	1.261	1.311	1.315	1.265	1.307	1.195	1.232	1.232	1.240
pos 4	1.326	1.425	1.407	1.246	1.246	1.195	1.356	1.323	1.265	1.276	1.365	1.335	1.311	1.269	1.382	1.284	1.307	1.319	1.344	1.335
pos 5	1.258	1.331	1.249	1.218	1.218	1.169	1.232	1.212	1.254	1.240	1.240	1.198	1.212	1.198	1.215	1.240	1.232	1.192	1.192	1.208
pos 6	1.167	1.278	1.209	1.023	1.023	0.983	1.147	1.185	1.226	1.265	1.147	1.160	1.121	1.141	1.112	1.192	1.153	1.132	1.106	1.166
pos 7	1.278	1.293	1.453	1.177	1.177	1.129	1.291	1.198	1.226	1.219	1.226	1.254	1.195	1.141	1.254	1.160	1.205	1.254	1.071	1.175
pos 8	1.352	1.434	1.425	1.282	1.282	1.229	1.331	1.340	1.340	1.365	1.374	1.428	1.315	1.299	1.477	1.323	1.361	1.276	1.352	1.348
avg	1.287	1.353	1.342	1.219	1.219	1.169	1.282	1.280	1.260	1.282	1.249	1.262	1.252	1.243	1.273	1.255	1.240	1.256	1.232	1.260
std dev	0.063	0.060	0.085	0.102	0.102	0.097	0.065	0.073	0.050	0.048	0.086	0.085	0.073	0.077	0.111	0.063	0.071	0.076	0.107	0.081
avg+std	1.350	1.412	1.427	1.321	1.321	1.267	1.347	1.353	1.310	1.329	1.335	1.347	1.325	1.321	1.384	1.318	1.311	1.332	1.339	1.341
avg-std	1.225	1.293	1.257	1.116	1.116	1.072	1.217	1.207	1.210	1.234	1.163	1.177	1.179	1.166	1.162	1.192	1.169	1.180	1.125	1.179
std %	4.86	4.42	6.36	8.40	8.40	8.33	5.10	5.69	3.95	3.74	6.87	6.73	5.82	6.22	8.70	5.04	5.72	6.05	8.70	6.45

Table III In-plane V_{21}, Shear Mode Measurements

V21	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pos 9	1.541	1.428	1.348	1.402	1.338	1.492	1.316	1.556	1.503	1.424	1.420	1.378	1.492	1.506	1.409	1.501	1.351	1.520	1.484	1.524
pos 10	1.494	1.498	1.427	1.447	1.415	1.562	1.492	1.584	1.538	1.459	1.424	1.410	1.555	1.546	1.488	1.574	1.401	1.603	1.574	1.597
pos 11	1.538	1.656	1.654	1.613	1.631	1.621	1.624	1.609	1.546	1.487	1.650	1.684	1.631	1.555	1.665	1.526	1.541	1.535	1.600	1.583
pos 12	1.334	1.488	1.526	1.549	1.498	1.476	1.553	1.403	1.522	1.449	1.586	1.597	1.546	1.445	1.593	1.427	1.522	1.459	1.556	1.473
avg	1.477	1.517	1.489	1.503	1.471	1.538	1.496	1.538	1.527	1.455	1.520	1.517	1.556	1.513	1.539	1.507	1.454	1.529	1.554	1.544
std dev	0.098	0.097	0.132	0.096	0.125	0.067	0.132	0.093	0.019	0.026	0.116	0.147	0.057	0.050	0.113	0.061	0.092	0.059	0.050	0.057
avg+std	1.574	1.615	1.621	1.599	1.596	1.604	1.628	1.631	1.546	1.481	1.636	1.664	1.613	1.563	1.652	1.568	1.546	1.588	1.603	1.601
avg-std	1.379	1.420	1.357	1.407	1.345	1.471	1.364	1.445	1.508	1.429	1.404	1.370	1.498	1.463	1.426	1.446	1.362	1.470	1.504	1.487
std %	6.61	6.40	8.87	6.37	8.52	4.34	8.82	6.03	1.25	1.77	7.65	9.68	3.69	3.32	7.33	4.06	6.34	3.86	3.20	3.70

Table IV In-plane V_{22}, Longitudinal Mode Measurements

V22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pos 9	2.332	2.201	2.129	2.023	2.109	2.325	2.033	2.383	2.418	2.092	2.243	2.185	2.310	2.327	2.212	2.359	2.125	2.387	2.361	2.368
pos 10	2.250	2.277	2.222	2.192	2.102	2.186	2.162	2.477	2.313	2.207	2.311	2.153	2.211	2.381	2.329	2.244	2.270	2.482	2.219	2.441
pos 11	2.239	2.339	2.549	2.419	2.319	2.385	2.556	2.301	2.251	2.301	2.383	2.461	2.327	2.308	2.603	2.278	2.326	2.404	2.513	2.495
pos 12	2.221	2.305	2.386	2.402	2.166	2.165	2.424	2.178	2.091	2.293	2.475	2.487	2.168	2.284	2.451	2.246	2.354	2.270	2.421	2.320
avg	2.260	2.281	2.321	2.259	2.174	2.265	2.294	2.335	2.268	2.223	2.353	2.322	2.254	2.325	2.399	2.282	2.269	2.386	2.378	2.406
std dev	0.049	0.059	0.185	0.188	0.101	0.107	0.239	0.127	0.137	0.097	0.099	0.177	0.077	0.041	0.168	0.054	0.102	0.088	0.123	0.078
avg+std	2.310	2.340	2.507	2.447	2.275	2.372	2.533	2.462	2.405	2.321	2.452	2.498	2.331	2.366	2.566	2.336	2.370	2.474	2.502	2.484
avg-std	2.211	2.222	2.136	2.070	2.073	2.158	2.055	2.208	2.132	2.126	2.254	2.145	2.177	2.284	2.231	2.228	2.167	2.298	2.255	2.329
std %	2.18	2.57	7.98	8.33	4.64	4.72	10.42	5.43	6.03	4.37	4.22	7.61	3.42	1.77	6.98	2.36	4.49	3.68	5.19	3.22

APPENDIX B

LOAD_DEPENDENT FRICTION MATERIAL PROPERTIES

For a few of the pads and positions we measured the ultrasonic velocity over a range of loads. In order to provide some background or perspective we present in Figures B-1 through B-8 which are results obtained on seven different friction materials. Figure B-1 shows typical load-dependent results on all modes obtained on a highly non-linear, load dependent friction material. This illustrates that even on this friction material which has significant load dependence for the out-of-plane modes, there is essentially no load dependence for the in-plane modes.

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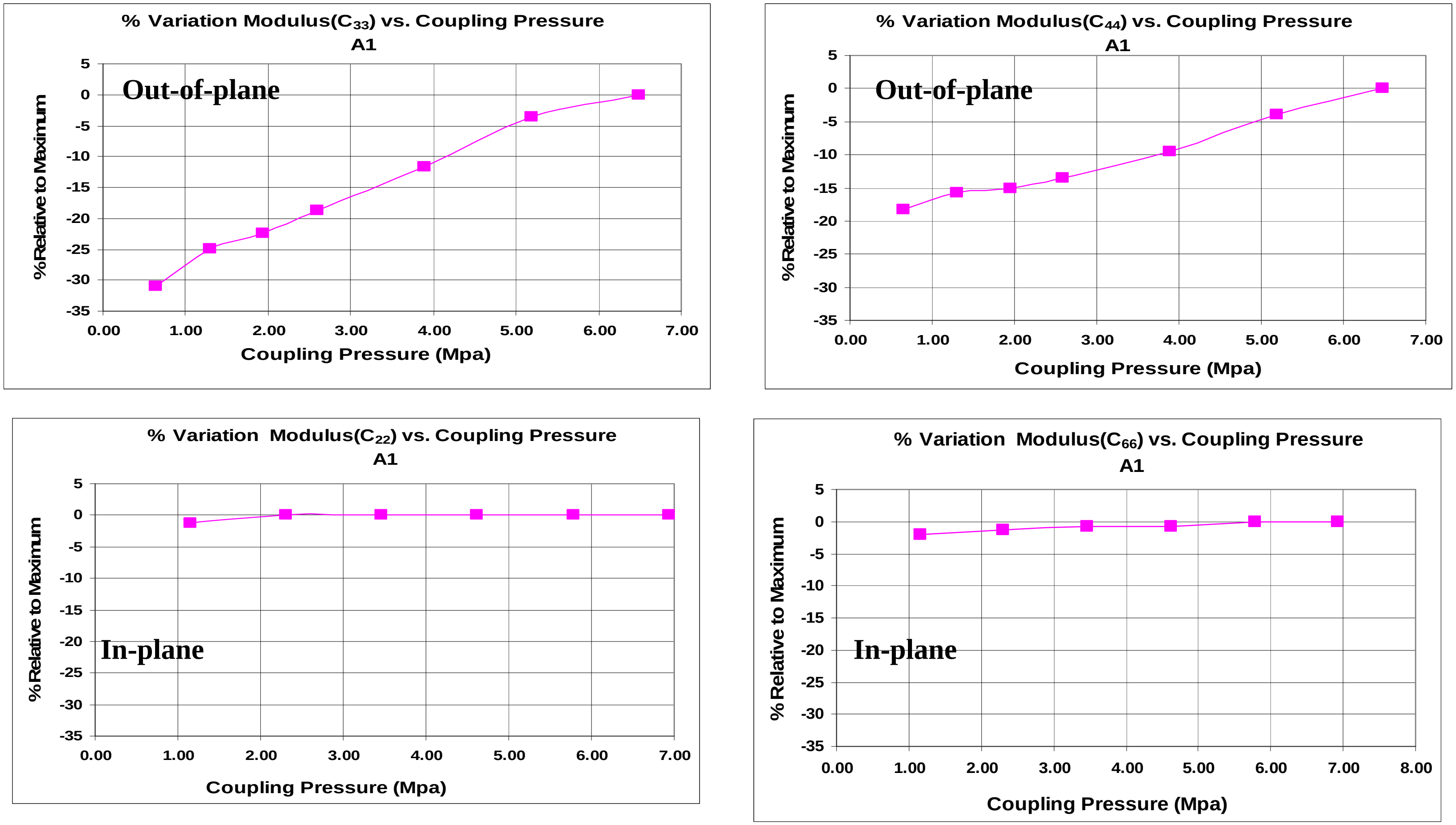
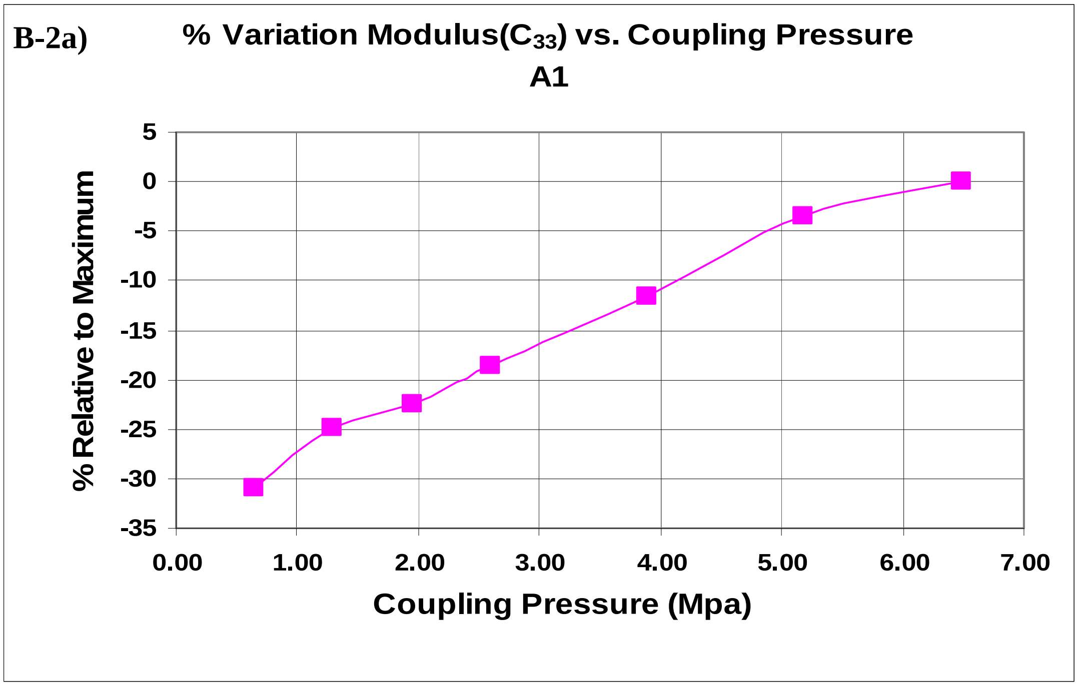


Figure B-1 Load-dependence for the for velocity modes measured on as-manufactured brake pads. Note only the out-of-plane modes C_{33} and C_{44} exhibit significant load dependence.



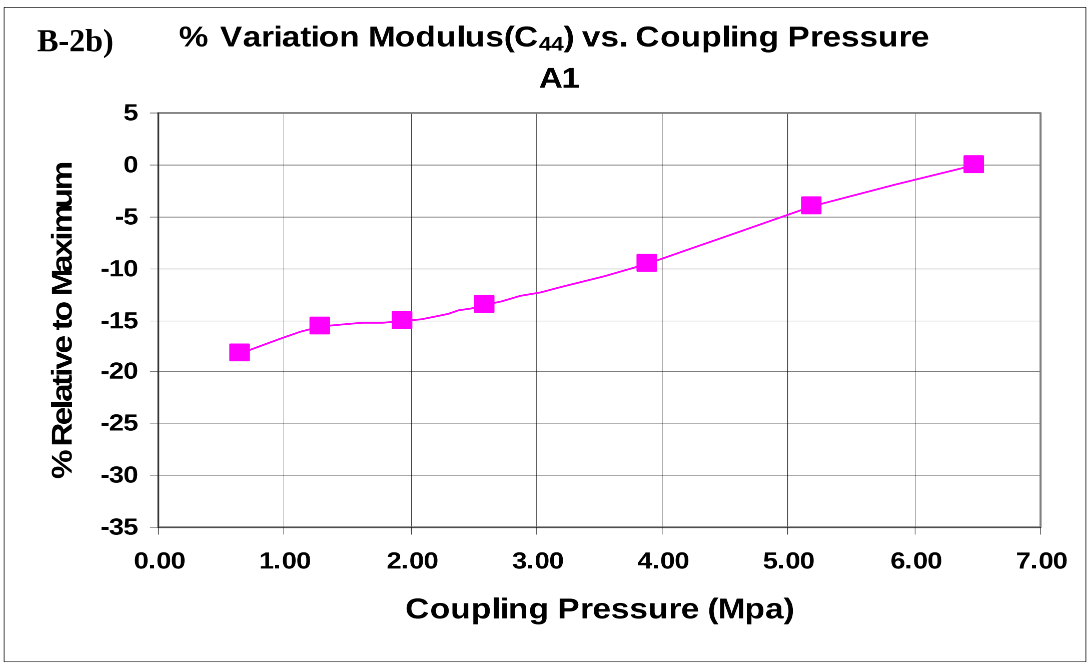
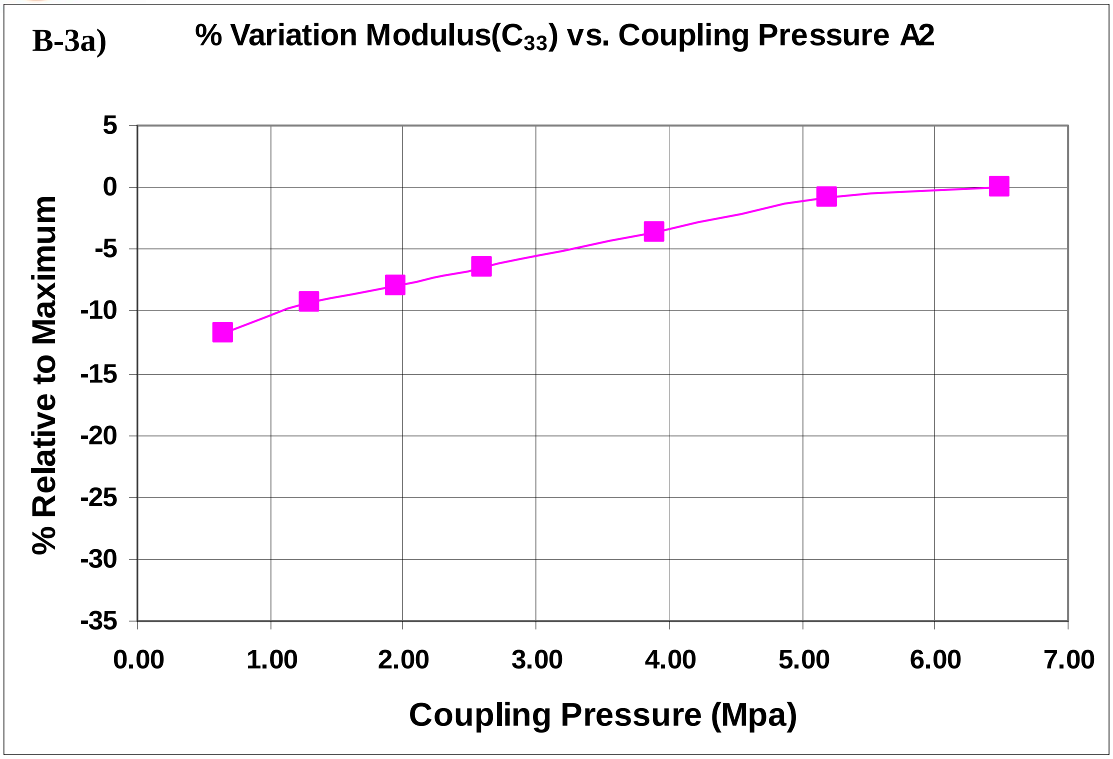


Figure B-2 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for highly non-linear friction material type A1.



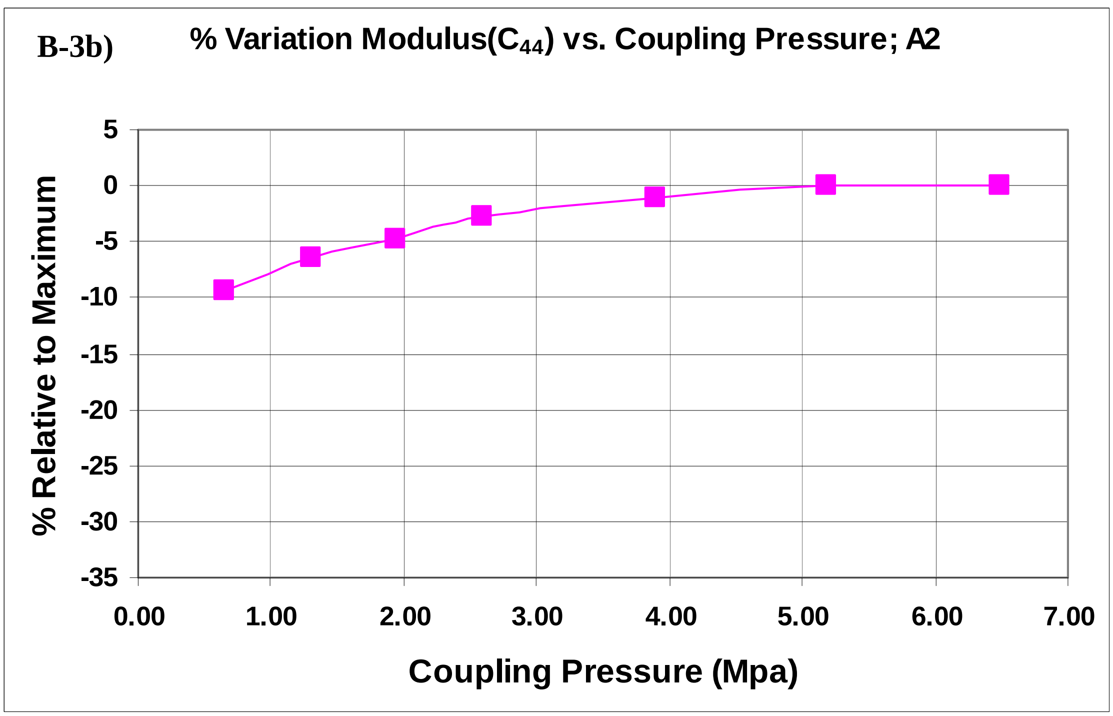
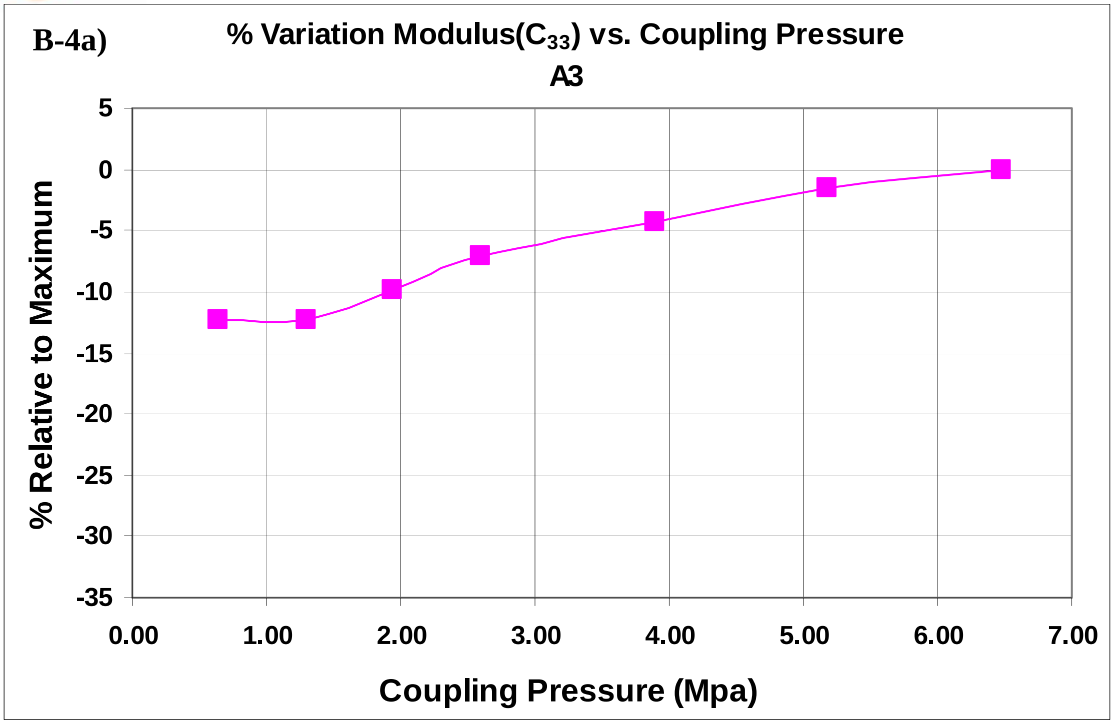


Figure B-3 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for moderately non-linear friction material type A2.



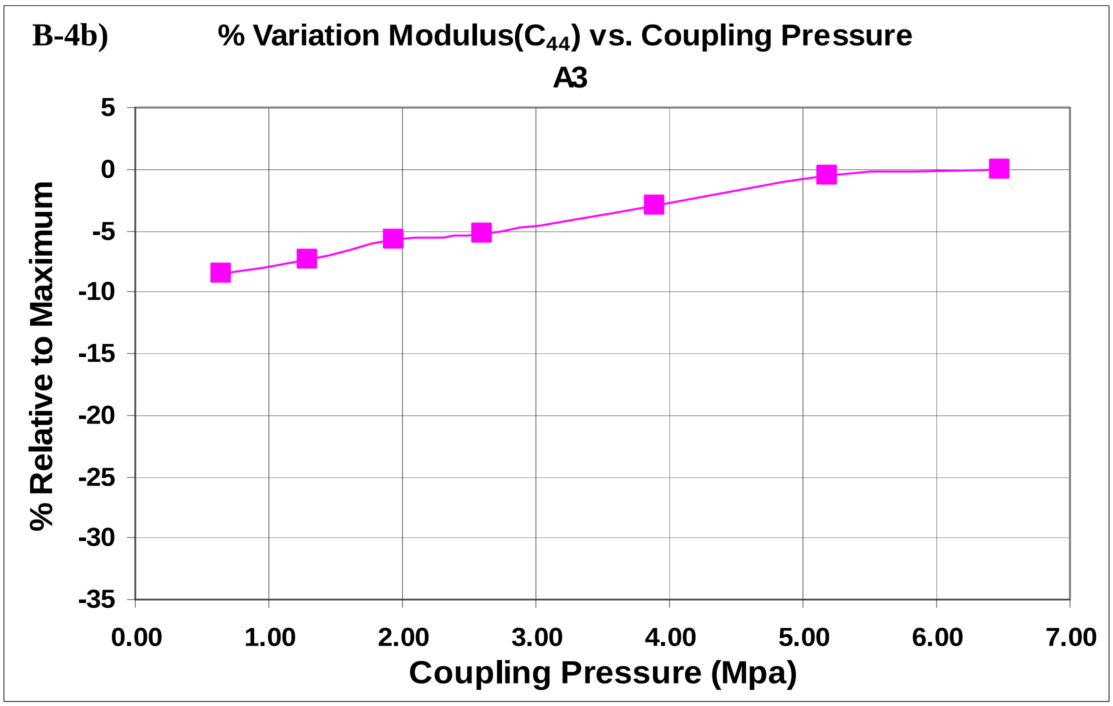
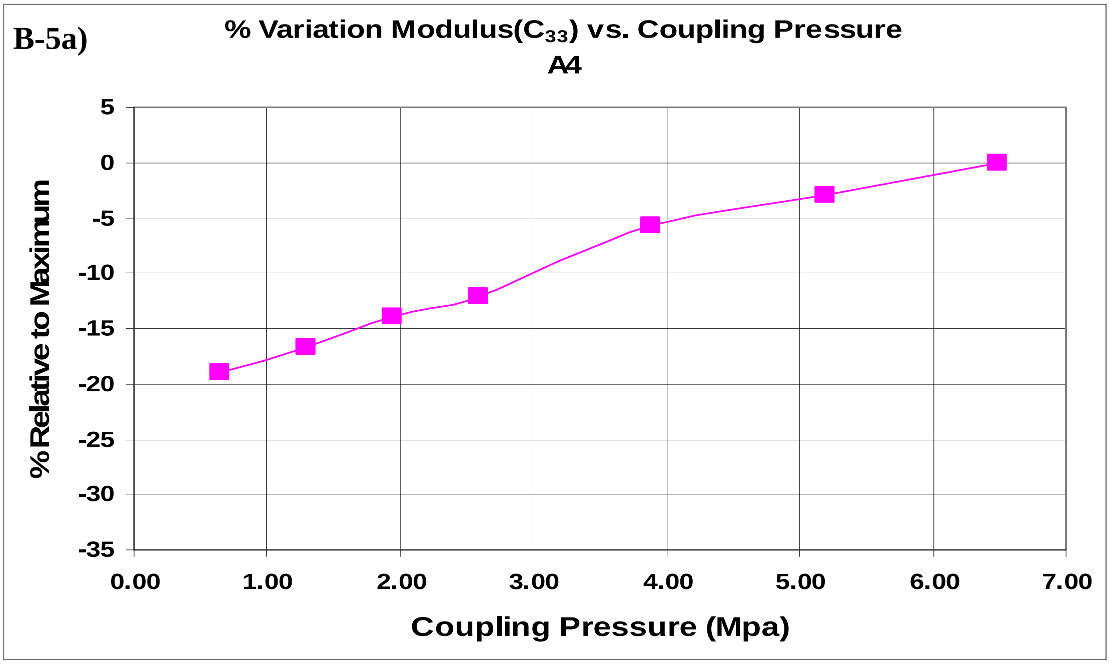


Figure B-4 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for moderately non-linear friction material type A3.



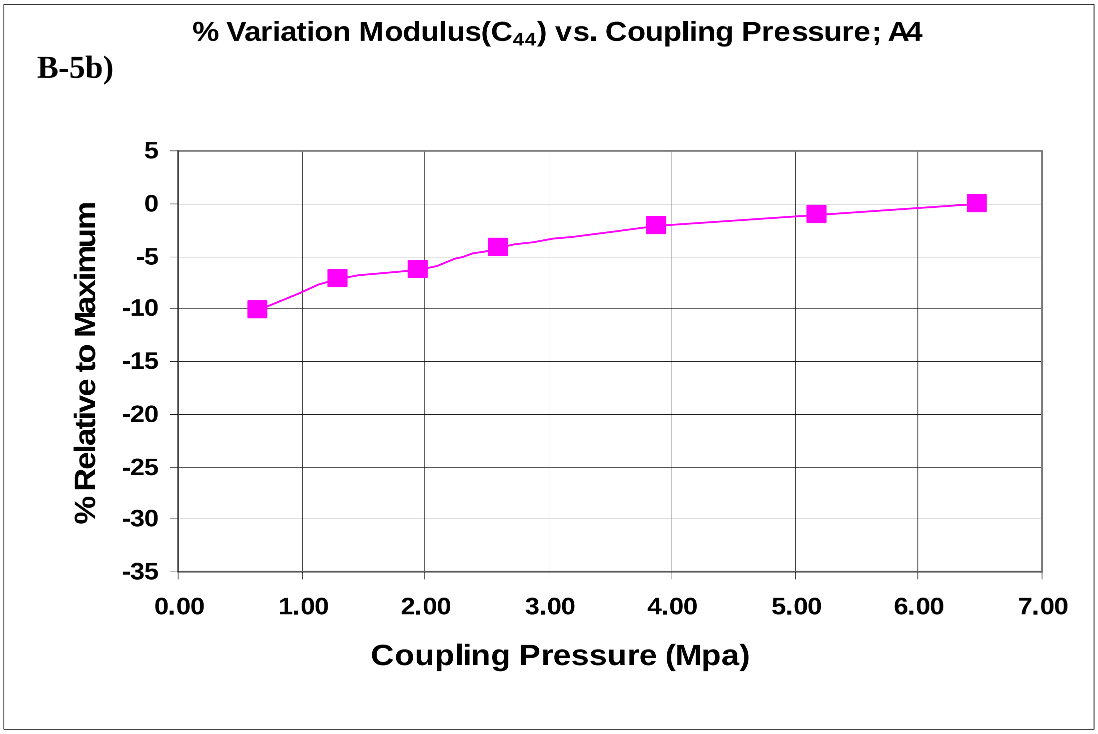
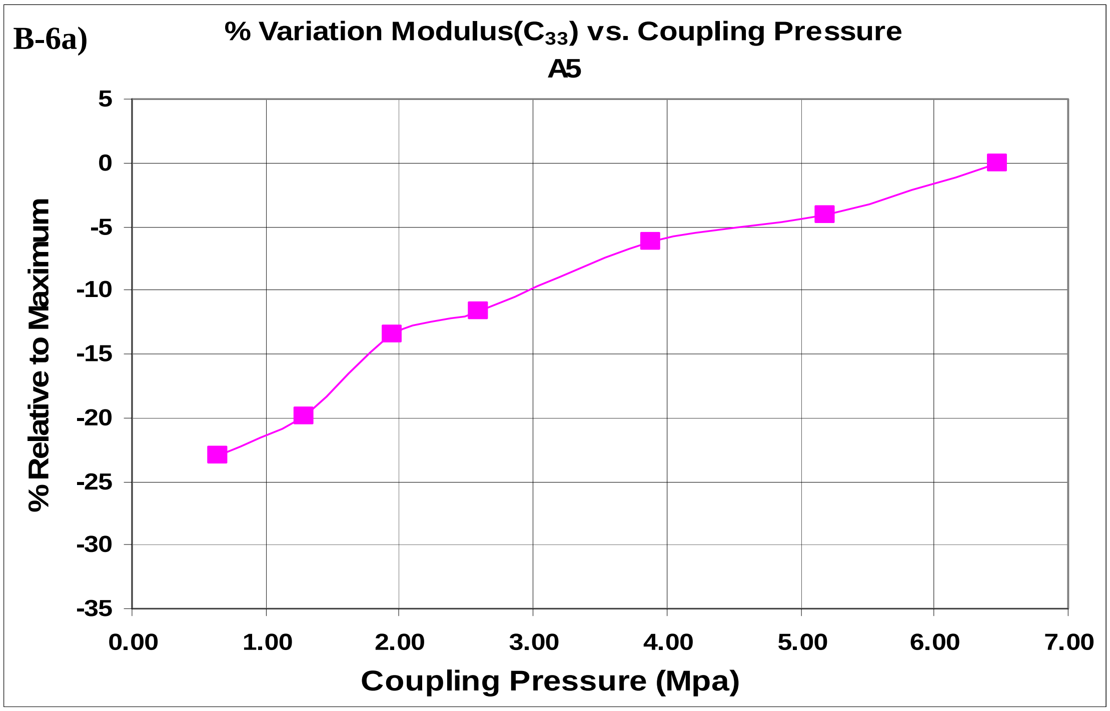


Figure B-5 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for moderately non-linear friction material type A4.



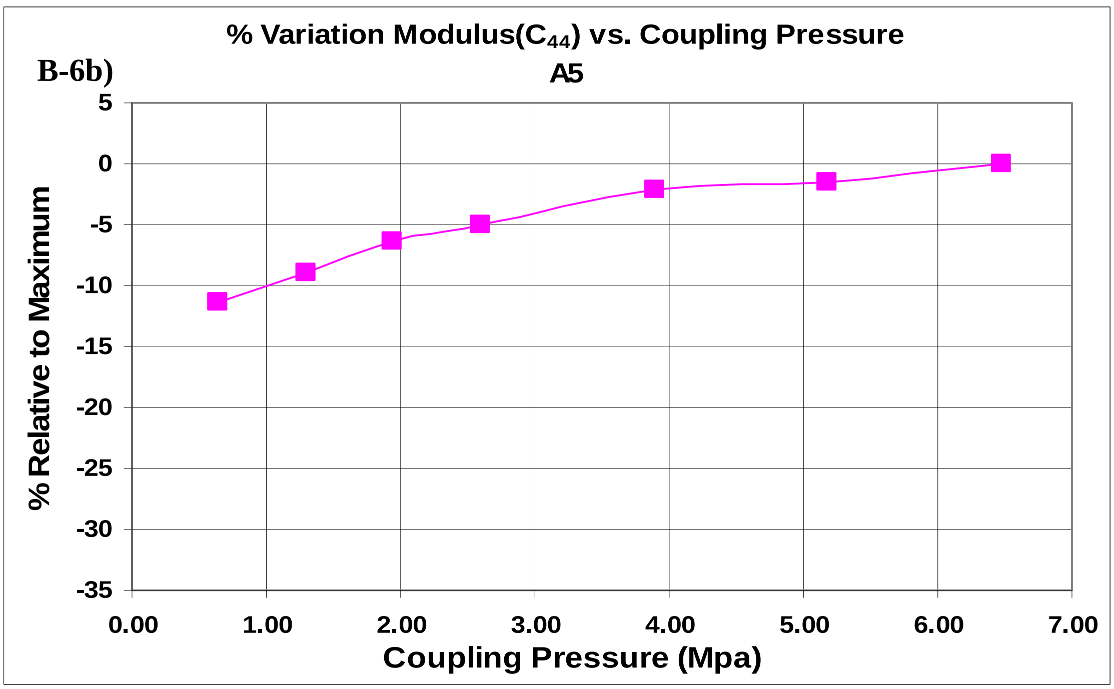
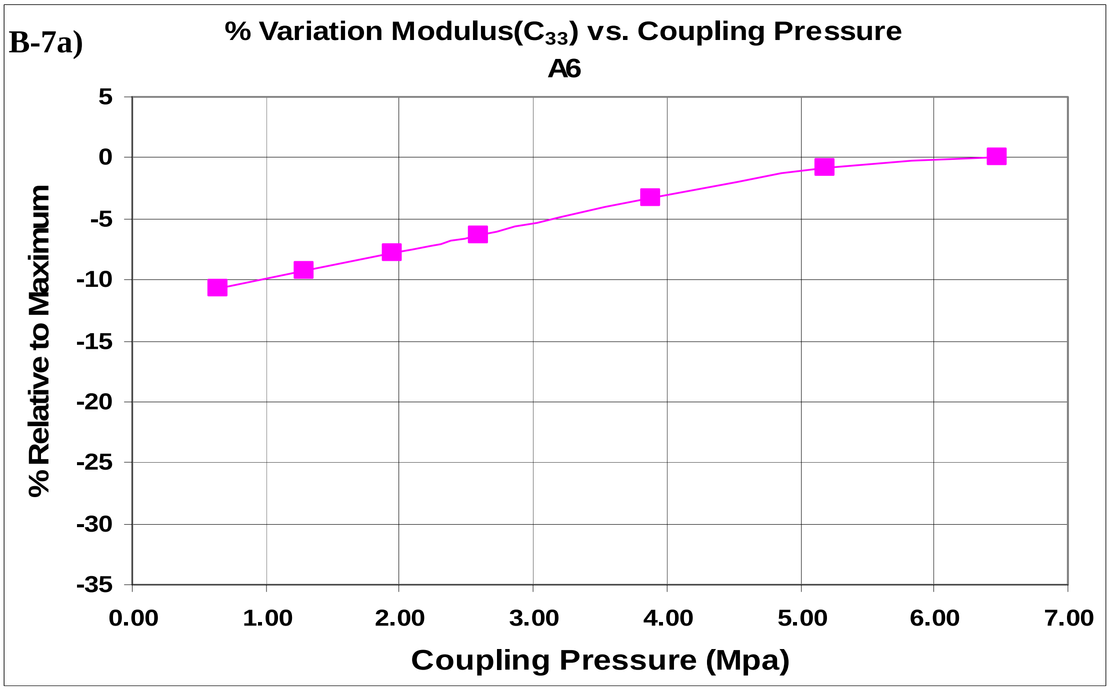


Figure B-6 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for highly non-linear friction material type A5.



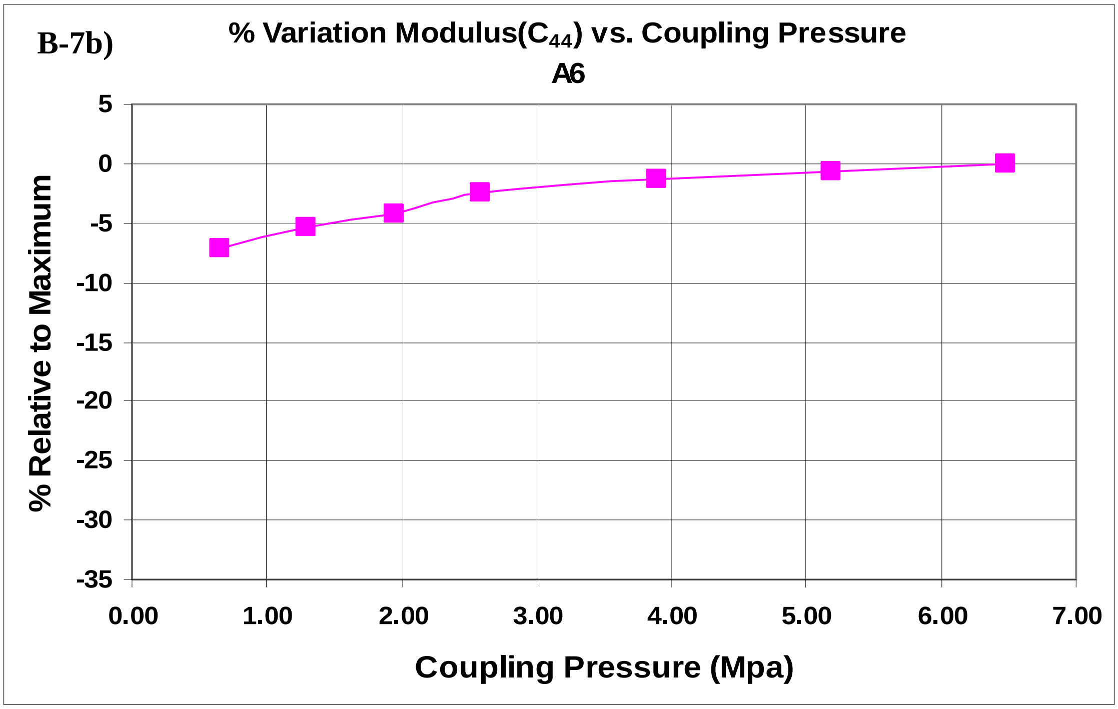


Figure B-7 Load-dependence for the for velocity modes a) V_{33} (C_{33}) and b)V_{32} (C_{44}) for moderately non-linear friction material type A6.

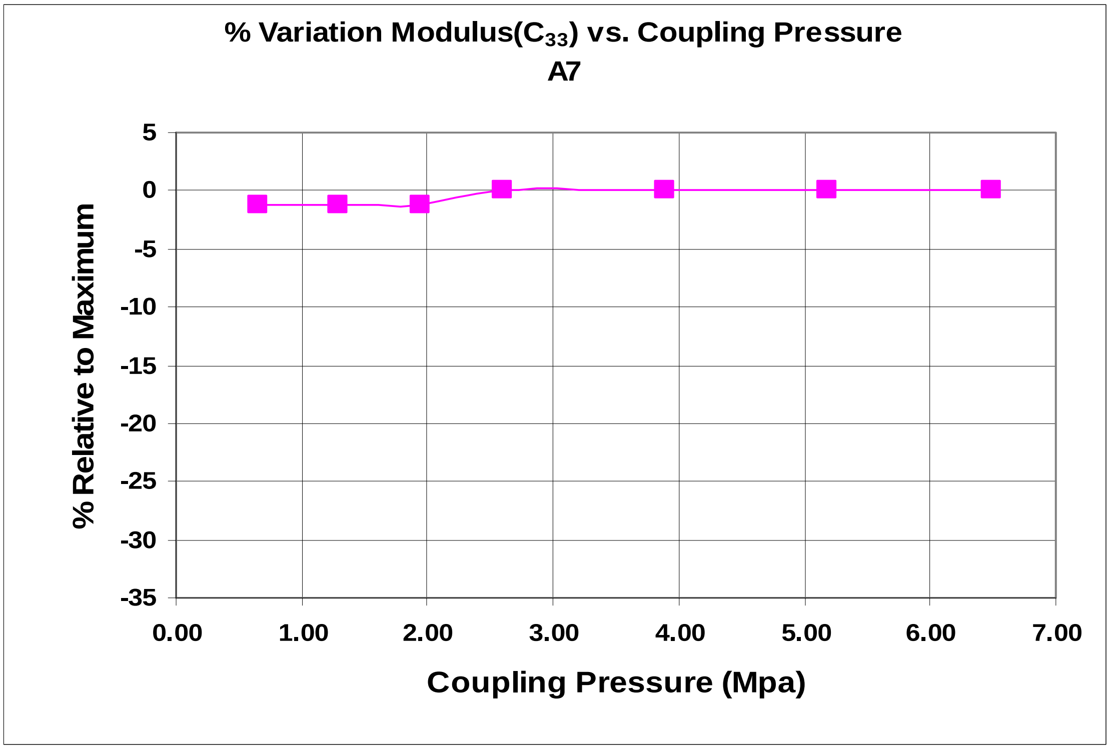


Figure B-8 Load-dependence for the for velocity mode V_{33} (C_{33}) for linear friction material type A7.

APPENDIX C

ELASTIC MODULUS CALCULATIONS

For the intact, as-manufactured pads, we measure 4 of the five ultrasonic velocities needed to compute the elastic constants and engineering constants. The 5th elastic constant requires destructive analysis of the pad to measure a velocity, V_{45} propagating along a non-principal axis. The density is also required. Because we got lazy we only measured one sample destructively in or to obtain the complete elastic constant matrix and density. The results are presented below for three cases.

Case I: Test sample average

Results obtained on samples extracted from single pad. Two samples are used, one is a rectangular piece 15 mm by 20 mm by 7 mm and the second is a smaller piece cut at 45 degrees to the "3" axis. We then applied standard laboratory measurement methods (SAE specification J2725). For this specification a coupling pressure of 4 MPa was used. This is less than that employed for the intact samples. The engineering and elastic constants were extracted from the data obtained on these two sample pieces.

Case II: Pad Average

Using the density and V45 value obtained in the Case I analysis and the velocities measured on the same intact sample, we calculated the engineering and elastic constants. This yielded a better estimate of the pad average. It also gave us some idea of our ability to quantitatively measure the friction materials in the intact condition.

Case III: Group Average

Using the density and V45 value obtained in the Case I analysis and the velocities measured on the same intact sample, we calculated the engineering and elastic constants. This yielded a better estimate of the group average.

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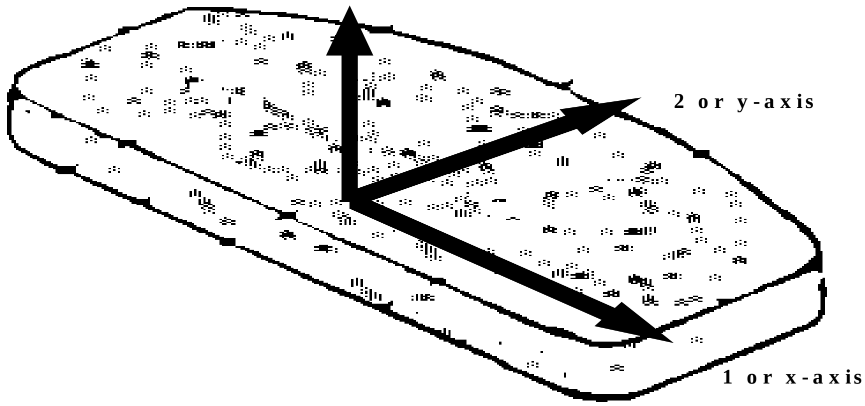
Case I: Test Destructive Laboratory Sample Average (Sample 8)

Disc Pad Coordinate Definition



Ultrasound Velocity

V33	<V22;V11>	<V31,V32>	V12	Rho	V45
Km/sec	Km/sec	Km/sec	Km/sec	Gm/cc	km/sec
1.227	2.486	1.089	1.565	2.661	0.973

Elastic Constants

C11	C22	C33	C44	C55	C66	C12	C13
Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa
16.44	16.44	4.01	3.15	3.15	6.51	3.41	2.41

Engineering Constants

	Gpa	Ksi	
Ex=Ey	14.74	2136.7	Young' Modulus(in-Plane)
v12=v21	0.13	0.13	Poisson's Ratio
Ez=E3	3.42	496.2	Young's Modulus (out-of Plane)
v31=v32	0.12	0.12	Poisson's Ratio
v23=v13	0.52	0.52	Poisson's Ratio
G13=G23	3.15	457.2	Shear Modulus(in-Plane)
G12	6.51	944.6	Shear Modulus (out-of-Plane)

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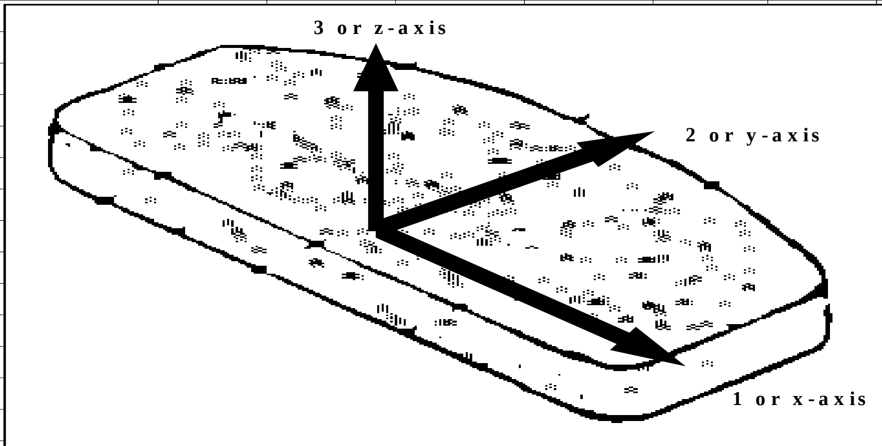
Case II: Pad Average (Intact Sample 8)

Disc Pad Coordinate Definition



Ultrasound Velocity

V33	<V22;V11>	<V31,V32>	V12	Rho	V45
Km/sec	Km/sec	Km/sec	Km/sec	Gm/cc	km/sec
1.280	2.335	1.089	1.538	2.661	0.973

Elastic Constants

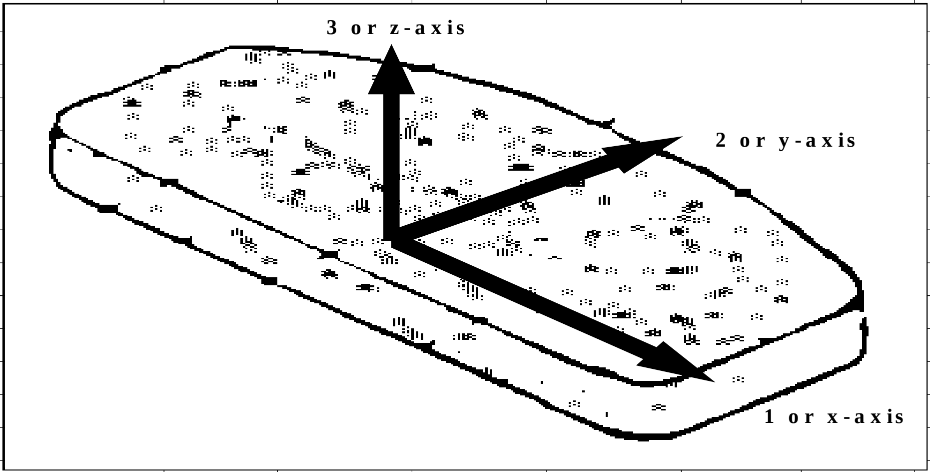
C11	C22	C33	C44	C55	C66	C12	C13
Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa
14.50	14.50	4.36	3.15	3.15	6.29	1.91	2.44

Engineering Constants

	Gpa	Ksi	
Ex=Ey	13.12	1902.0	Young' Modulus(in-Plane)
v12=v21	0.04	0.04	Poisson's Ratio
Ez=E3	3.63	527.0	Young's Modulus (out-of Plane)
v31=v32	0.15	0.15	Poisson's Ratio
v23=v13	0.54	0.54	Poisson's Ratio
G13=G23	3.15	457.4	Shear Modulus(in-Plane)
G12	6.29	912.7	Shear Modulus (out-of-Plane)

Case III: Group Average 20 Brake Pads

Disc Pad Coordinate Definition



Ultrasound Velocity

V33	<V22;V11>	<V31,V32>	V12	Rho	V45
Km/sec	Km/sec	Km/sec	Km/sec	Gm/cc	km/sec
1.261	2.303	1.069	1.512	2.661	0.973

Elastic Constants

C11	C22	C33	C44	C55	C66	C12	C13
Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa	Gpa
14.11	14.11	4.23	3.04	3.04	6.08	1.95	2.16

Engineering Constants

	Gpa	Ksi	
Ex=Ey	12.95	1877.8	Young' Modulus(in-Plane)
v12=v21	0.06	0.06	Poisson's Ratio
Ez=E3	3.65	528.9	Young's Modulus (out-of Plane)
v31=v32	0.13	0.13	Poisson's Ratio
v23=v13	0.48	0.48	Poisson's Ratio
G13=G23	3.04	440.9	Shear Modulus(in-Plane)
G12	6.08	882.0	Shear Modulus (out-of-Plane)

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