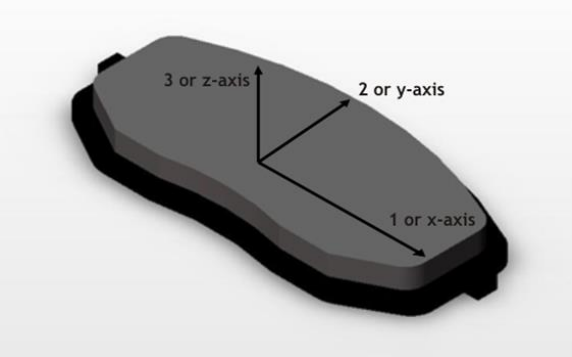
ETEK Enhanced Data Files

In order to improve the usefulness of engineering property data for NVH analysis IMS Inc. has formulated a specific measurement procedure and analysis routine which combines the effects of pre-load and temperature. This data format is currently being required by several OE's and first tier brake manufactures.

Standard ambient temperature measurements are made in accordance with SAE J2725 at a fixed preload. Subsequently, the preload dependence of the out-of-plane modulus are measured over the range from 0.5 MPa (5 bar) to 4.0 MPa (40 bar) and the temperature dependence of modulus is measure over the temperature range from 20°C to 325°C. An Excel macro is then used to generate a complete set of engineering properties as a function both temperature and preload. Representative results are illustrated below:

The following enhanced ETEK data Excel files contain average ultrasonic velocity data that were measured on three samples from a single friction material using the ETEK as a function of load and pressure as outlined in the SAE specification J2725. Density of the three samples was also measured. Young's, Shear Modulus, Poisson's ratios and elastic constants were calculated using these values.



This diagram shown above illustrates the coordinate system used for ETEK measurements and the tensor notation associated with the velocity measurements in relation to a brake pad. The first value indicates the direction of the sound propagation and the second number the polarization of the wave. A V_{33} measurement is a compressional measurement thru the thickness of the pad whereas a V_{32} is a shear measurement thru-the-thickness with the polarization in the 2-direction.

Enhanced Measurement in Tabular Format

IMS Pressure Dependence at @ RT (ambient)							
Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45
°C	MPa	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs
23	0.5	2.42	1.16	2.39	0.94	1.42	0.89
23	1.0	2.42	1.18	2.39	0.94	1.42	0.89
23	1.5	2.42	1.20	2.39	0.95	1.42	0.89
23	2.0	2.42	1.22	2.39	0.95	1.42	0.89
23	2.5	2.42	1.24	2.39	0.96	1.42	0.89
23	3.0	2.42	1.27	2.39	0.96	1.42	0.90
23	3.5	2.42	1.29	2.39	0.97	1.42	0.90
23	4.0	2.42	1.31	2.39	0.97	1.42	0.90
23	4.5	2.42	1.34	2.39	0.98	1.42	0.90
23	5.0	2.42	1.36	2.39	0.98	1.42	0.91
23	5.5	2.42	1.39	2.39	0.99	1.42	0.91

The first table in the enhanced data shows average (of 3 samples) V_{33} and V_{32} data measured at ambient temperature as a function of coupling pressure (0.5-5.5 MPa). The in-plane measurements are not sensitive to load, thus those values remain the same. The load measurements are provided in the standard ETEK measurement.

Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
in-plane	out-plane	in-plane	out-plane				C11,C22	C33	C44,C55	C66	C12	C13
Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	v12=v21	v31=v32	v23=v13	GPa	GPa	GPa	GPa	GPa	GPa
11.80	2.69	4.90	2.14	0.20	0.12	0.54	13.78	3.23	2.14	4.90	3.97	2.19
11.70	2.73	4.90	2.16	0.19	0.13	0.56	13.78	3.35	2.16	4.90	3.97	2.34
11.59	2.77	4.90	2.17	0.18	0.14	0.59	13.78	3.48	2.17	4.90	3.97	2.49
11.49	2.81	4.90	2.19	0.17	0.15	0.61	13.78	3.60	2.19	4.90	3.97	2.65
11.38	2.86	4.90	2.21	0.16	0.16	0.63	13.78	3.74	2.21	4.90	3.97	2.80
11.27	2.90	4.90	2.24	0.15	0.17	0.65	13.78	3.88	2.24	4.90	3.97	2.96
11.16	2.94	4.90	2.26	0.14	0.18	0.67	13.78	4.03	2.26	4.90	3.97	3.11
11.05	2.98	4.90	2.29	0.13	0.18	0.68	13.78	4.18	2.29	4.90	3.97	3.27
10.94	3.02	4.90	2.32	0.11	0.19	0.70	13.78	4.34	2.32	4.90	3.97	3.42
10.82	3.07	4.90	2.35	0.10	0.20	0.71	13.78	4.51	2.35	4.90	3.97	3.58
10.71	3.11	4.90	2.38	0.09	0.21	0.72	13.78	4.68	2.38	4.90	3.97	3.73

Calculations of Young's modulus, shear modulus, Poisson's ration and elastic constants are then made from these averaged values.

IMS Temperature Dependence at @ 30 bar (3 MPa)							
Temp.	**Pressure**	**Rho**	**V33**	**<V22;V11>**	**<V31;V32>**	**V12**	**V45**
°C	MPa	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs
23	3.00	2.42	1.27	2.39	0.96	1.42	0.90
25	3.00	2.42	1.27	2.39	0.96	1.42	0.90
75	3.00	2.42	1.20	2.29	0.93	1.42	0.88
100	3.00	2.42	1.17	2.25	0.91	1.41	0.87
125	3.00	2.42	1.14	2.21	0.90	1.39	0.86
175	3.00	2.42	1.10	2.13	0.86	1.34	0.83
200	3.00	2.42	1.09	2.10	0.84	1.31	0.81
225	3.00	2.42	1.08	2.07	0.82	1.27	0.79
275	3.00	2.42	1.07	2.01	0.78	1.17	0.73
300	3.00	2.42	1.06	1.99	0.76	1.12	0.71
325	3.00	2.42	1.05	1.97	0.74	1.05	0.67

An elevated temperature measurement (ambient to 325°C in 50°C increments) is then made for the 4 independent modes (V_{33}, V_{32}, V_{22}, V_{21}) using a referenced coupling pressure.

Young's Modulus		**Shear Modulus**		**Poisson's Ratio**			**Elastic Constants**					
in-plane	out-plane	in-plane	out-plane				**C11,C22**	**C33**	**C44,C55**	**C66**	**C12**	**C13**
Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	**v12=v21**	**v31=v32**	**v23=v13**	GPa	GPa	GPa	GPa	GPa	GPa
11.27	2.90	4.90	2.24	0.15	0.17	0.65	13.78	3.88	2.24	4.90	3.97	2.96
11.27	2.90	4.90	2.24	0.15	0.17	0.65	13.82	3.90	2.24	4.90	4.01	2.98
10.98	2.77	4.88	2.09	0.12	0.15	0.59	12.72	3.46	2.09	4.88	2.95	2.33
10.74	2.69	4.81	2.02	0.12	0.14	0.57	12.24	3.29	2.02	4.81	2.61	2.11
10.45	2.60	4.71	1.94	0.11	0.14	0.55	11.79	3.14	1.94	4.71	2.37	1.95
9.72	2.42	4.38	1.79	0.11	0.14	0.56	11.00	2.93	1.79	4.38	2.24	1.84
9.29	2.31	4.16	1.71	0.12	0.14	0.58	10.66	2.86	1.71	4.16	2.33	1.88
8.82	2.21	3.91	1.63	0.13	0.15	0.61	10.35	2.81	1.63	3.91	2.52	1.97
7.73	1.97	3.34	1.47	0.16	0.18	0.70	9.82	2.78	1.47	3.34	3.13	2.29
7.11	1.83	3.02	1.39	0.18	0.19	0.74	9.60	2.80	1.39	3.02	3.55	2.51
6.45	1.70	2.69	1.31	0.20	0.21	0.78	9.40	2.84	1.31	2.69	4.02	2.77

Calculations are then made from these velocities for Young's modulus, shear modulus, Poisson's ration and elastic constants are made from these averaged values.

IMS Temperature Dependence at @ 15 bar (1.5 MPa)							
Temp.	**Pressure**	**Rho**	**V33**	**<V22;V11>**	**<V31;V32>**	**V12**	**V45**
°C	MPa	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs
23	1.50	2.42	1.20	2.39	0.95	1.42	0.89
25	1.50	2.42	1.20	2.39	0.95	1.42	0.89
75	1.50	2.42	1.13	2.29	0.92	1.42	0.88
100	1.50	2.42	1.10	2.25	0.90	1.41	0.87
125	1.50	2.42	1.08	2.21	0.88	1.39	0.86
175	1.50	2.42	1.04	2.13	0.85	1.34	0.82
200	1.50	2.42	1.03	2.10	0.83	1.31	0.80
225	1.50	2.42	1.02	2.07	0.81	1.27	0.78
275	1.50	2.42	1.01	2.01	0.77	1.17	0.73
300	1.50	2.42	1.00	1.99	0.75	1.12	0.70
325	1.50	2.42	0.99	1.97	0.73	1.05	0.67

Young's Modulus		**Shear Modulus**		**Poisson's Ratio**			**Elastic Constants**					
in-plane	out-plane	in-plane	out-plane				**C11,C22**	**C33**	**C44,C55**	**C66**	**C12**	**C13**
Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	**v12=v21**	**v31=v32**	**v23=v13**	GPa	GPa	GPa	GPa	GPa	GPa
11.59	2.77	4.90	2.17	0.18	0.14	0.59	13.78	3.48	2.17	4.90	3.97	2.49
11.60	2.78	4.90	2.18	0.18	0.14	0.59	13.82	3.49	2.18	4.90	4.01	2.52
11.29	2.65	4.88	2.03	0.16	0.12	0.51	12.72	3.10	2.03	4.88	2.95	1.88
11.04	2.57	4.81	1.96	0.15	0.11	0.48	12.24	2.94	1.96	4.81	2.61	1.67
10.74	2.48	4.71	1.89	0.14	0.11	0.47	11.79	2.81	1.89	4.71	2.37	1.53
10.00	2.31	4.38	1.74	0.14	0.11	0.47	11.00	2.62	1.74	4.38	2.24	1.45
9.56	2.21	4.16	1.66	0.15	0.12	0.50	10.66	2.56	1.66	4.16	2.33	1.50
9.08	2.11	3.91	1.58	0.16	0.13	0.54	10.35	2.51	1.58	3.91	2.52	1.61
7.96	1.89	3.34	1.43	0.19	0.15	0.64	9.82	2.49	1.43	3.34	3.13	1.97
7.32	1.77	3.02	1.35	0.21	0.17	0.69	9.60	2.50	1.35	3.02	3.55	2.20
6.63	1.63	2.69	1.27	0.23	0.18	0.75	9.40	2.54	1.27	2.69	4.02	2.46

The load and temperature data is then curve fit and velocity data is interpolated or extrapolated for additional loads and temperatures. The table above shows 15 bar (1.5 MPa) for temperatures of ambient (25°C) to 325°C in 50°C increments. Note the blue highlighted rows indicated interpolated data.

IMS Temperature Dependence at @ 5 bar (0.5 MPa)

Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45	Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
								in-plane	out-plane	in-plane	out-plane				C11,C22	C33	C44,C55	C66	C12	C13
°C	MPa	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs	Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	v12=v21	v31=v32	v23=v13	GPa	GPa	GPa	GPa	GPa	GPa
23	0.50	2.42	1.16	2.39	0.94	1.42	0.89	11.80	2.69	4.90	2.14	0.20	0.12	0.54	13.78	3.23	2.14	4.90	3.97	2.19
25	0.50	2.42	1.16	2.39	0.94	1.42	0.89	11.80	2.70	4.90	2.14	0.20	0.12	0.54	13.82	3.24	2.14	4.90	4.01	2.21
75	0.50	2.42	1.09	2.29	0.91	1.42	0.88	11.49	2.56	4.88	2.00	0.18	0.10	0.45	12.72	2.88	2.00	4.88	2.95	1.58
100	0.50	2.42	1.06	2.25	0.89	1.41	0.87	11.23	2.48	4.81	1.93	0.17	0.09	0.42	12.24	2.74	1.93	4.81	2.61	1.38
125	0.50	2.42	1.04	2.21	0.88	1.39	0.85	10.92	2.40	4.71	1.86	0.16	0.09	0.40	11.79	2.62	1.86	4.71	2.37	1.24
175	0.50	2.42	1.00	2.13	0.84	1.34	0.82	10.16	2.23	4.38	1.71	0.16	0.09	0.40	11.00	2.44	1.71	4.38	2.24	1.17
200	0.50	2.42	0.99	2.10	0.82	1.31	0.80	9.72	2.14	4.16	1.63	0.17	0.10	0.43	10.66	2.38	1.63	4.16	2.33	1.24
225	0.50	2.42	0.98	2.07	0.80	1.27	0.78	9.24	2.05	3.91	1.56	0.18	0.11	0.48	10.35	2.34	1.56	3.91	2.52	1.36
275	0.50	2.42	0.98	2.01	0.76	1.17	0.73	8.11	1.84	3.34	1.41	0.21	0.14	0.60	9.82	2.31	1.41	3.34	3.13	1.75
300	0.50	2.42	0.98	1.99	0.74	1.12	0.70	7.46	1.72	3.02	1.33	0.23	0.15	0.66	9.60	2.33	1.33	3.02	3.55	1.99
325	0.50	2.42	0.99	1.97	0.72	1.05	0.67	6.76	1.60	2.69	1.26	0.25	0.17	0.72	9.40	2.36	1.26	2.69	4.02	2.27

The load and temperature data is then curve fit and velocity data is interpolated or extrapolated for additional loads and temperatures. The table above shows 5 bar (0.5 MPa) for temperatures of ambient (25°C) to 325°C in 50°C increments. Note the blue highlighted rows indicated interpolated data.

A table summarizes the results.

Summary

Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45	Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
								in-plane	out-plane	in-plane	out-plane				C11,C22	C33	C44,C55	C66	C12	C13
°C	Bar	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs	Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	v12=v21	v31=v32	v23=v13	GPa	GPa	GPa	GPa	GPa	GPa
25	5	2.42	1.16	2.39	0.94	1.42	0.89	11.80	2.69	4.90	2.14	0.20	0.12	0.54	13.78	3.23	2.14	4.90	3.97	2.19
25	10	2.42	1.18	2.39	0.94	1.42	0.89	11.70	2.73	4.90	2.16	0.19	0.13	0.56	13.78	3.35	2.16	4.90	3.97	2.34
25	15	2.42	1.20	2.39	0.95	1.42	0.89	11.59	2.77	4.90	2.17	0.18	0.14	0.59	13.78	3.48	2.17	4.90	3.97	2.49
25	20	2.42	1.22	2.39	0.95	1.42	0.89	11.49	2.81	4.90	2.19	0.17	0.15	0.61	13.78	3.60	2.19	4.90	3.97	2.65
25	25	2.42	1.24	2.39	0.96	1.42	0.89	11.38	2.86	4.90	2.21	0.16	0.16	0.63	13.78	3.74	2.21	4.90	3.97	2.80
25	30	2.42	1.27	2.39	0.96	1.42	0.90	11.27	2.90	4.90	2.24	0.15	0.17	0.65	13.78	3.88	2.24	4.90	3.97	2.96
25	35	2.42	1.29	2.39	0.97	1.42	0.90	11.16	2.94	4.90	2.26	0.14	0.18	0.67	13.78	4.03	2.26	4.90	3.97	3.11
25	40	2.42	1.31	2.39	0.97	1.42	0.90	11.05	2.98	4.90	2.29	0.13	0.18	0.68	13.78	4.18	2.29	4.90	3.97	3.27
25	45	2.42	1.34	2.39	0.98	1.42	0.90	10.94	3.02	4.90	2.32	0.11	0.19	0.70	13.78	4.34	2.32	4.90	3.97	3.42
25	50	2.42	1.36	2.39	0.98	1.42	0.91	10.82	3.07	4.90	2.35	0.10	0.20	0.71	13.78	4.51	2.35	4.90	3.97	3.58
25	55	2.42	1.39	2.39	0.99	1.42	0.91	10.71	3.11	4.90	2.38	0.09	0.21	0.72	13.78	4.68	2.38	4.90	3.97	3.73
25	30	2.42	1.27	2.39	0.96	1.42	0.90	11.27	2.90	4.90	2.24	0.15	0.17	0.65	13.82	3.90	2.24	4.90	4.01	2.98
75	30	2.42	1.20	2.29	0.93	1.42	0.88	10.98	2.77	4.88	2.09	0.12	0.15	0.59	12.72	3.46	2.09	4.88	2.95	2.33
125	30	2.42	1.17	2.25	0.91	1.41	0.87	10.74	2.69	4.81	2.02	0.12	0.14	0.57	12.24	3.29	2.02	4.81	2.61	2.11
175	30	2.42	1.14	2.21	0.90	1.39	0.86	10.45	2.60	4.71	1.94	0.11	0.14	0.55	11.79	3.14	1.94	4.71	2.37	1.95
225	30	2.42	1.10	2.13	0.86	1.34	0.83	9.72	2.42	4.38	1.79	0.11	0.14	0.56	11.00	2.93	1.79	4.38	2.24	1.84
275	30	2.42	1.09	2.10	0.84	1.31	0.81	9.29	2.31	4.16	1.71	0.12	0.14	0.58	10.66	2.86	1.71	4.16	2.33	1.88
325	30	2.42	1.08	2.07	0.82	1.27	0.79	8.82	2.21	3.91	1.63	0.13	0.15	0.61	10.35	2.81	1.63	3.91	2.52	1.97

The final table show interpolated data for 20, 100, 200 and 300°C at loads of 5, 15 and 30 bar.

Interpolated/Extrapolated Values

Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45	Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
								in-plane	out-plane	in-plane	out-plane				C11,C22	C33	C44,C55	C66	C12	C13
°C	Bar	g/cm³	mm/µs	mm/µs	mm/µs	mm/µs	mm/µs	Ex=Ey (GPa)	Ez=E3 (GPa)	G12 (GPa)	G13=G23 (GPa)	v12=v21	v31=v32	v23=v13	GPa	GPa	GPa	GPa	GPa	GPa
20	5	2.42	1.16	2.39	0.94	1.42	0.89	11.80	2.69	4.90	2.14	0.20	0.12	0.54	13.78	3.23	2.14	4.90	3.97	2.19
20	15	2.42	1.18	2.39	0.94	1.42	0.89	11.70	2.73	4.90	2.16	0.19	0.13	0.56	13.78	3.35	2.16	4.90	3.97	2.34
20	30	2.42	1.20	2.39	0.95	1.42	0.89	11.59	2.77	4.90	2.17	0.18	0.14	0.59	13.78	3.48	2.17	4.90	3.97	2.49
100	5	2.42	1.06	2.25	0.89	1.41	0.87	11.23	2.48	4.81	1.93	0.17	0.09	0.42	12.24	2.74	1.93	4.81	2.61	1.38
100	15	2.42	1.10	2.25	0.90	1.41	0.87	11.04	2.57	4.81	1.96	0.15	0.11	0.48	12.24	2.94	1.96	4.81	2.61	1.67
100	30	2.42	1.17	2.25	0.91	1.41	0.87	10.74	2.69	4.81	2.02	0.12	0.14	0.57	12.24	3.29	2.02	4.81	2.61	2.11
200	5	2.42	0.99	2.10	0.82	1.31	0.80	9.72	2.14	4.16	1.63	0.17	0.10	0.43	10.66	2.38	1.63	4.16	2.33	1.24
200	15	2.42	1.03	2.10	0.83	1.31	0.80	9.56	2.21	4.16	1.66	0.15	0.12	0.50	10.66	2.56	1.66	4.16	2.33	1.50
200	30	2.42	1.09	2.10	0.84	1.31	0.81	9.29	2.31	4.16	1.71	0.12	0.14	0.58	10.66	2.86	1.71	4.16	2.33	1.88
300	5	2.42	0.98	1.99	0.74	1.12	0.70	7.46	1.72	3.02	1.33	0.23	0.15	0.66	9.60	2.33	1.33	3.02	3.55	1.99
300	15	2.42	1.00	1.99	0.75	1.12	0.70	7.32	1.77	3.02	1.35	0.21	0.17	0.69	9.60	2.50	1.35	3.02	3.55	2.20
300	30	2.42	1.06	1.99	0.76	1.12	0.71	7.11	1.83	3.02	1.39	0.18	0.19	0.74	9.60	2.80	1.39	3.02	3.55	2.51

Enhanced Measurement Data in Graphical Format

The Figures below illustrate the in-plane and out-of-plane Young's modulus as a function of both temperature and preload.