Analysis of Friction Material
ABC
Supplied by ABC Company

Submitted: Date submitted

By:

Industrial Measurement Systems, Inc.
2760 Beverly Dr. #4
Aurora, IL 60502

Under the Direction of: Customer Name
Customer Address

P.O. # 12345

Report on the Analysis of Friction Material
ABC

Introduction

Ultrasonic methods were used to characterize the ABC friction material. This analysis was carried out using the **ETEK** instrument manufactured by Industrial Measurement Systems Inc. The **ETEK** system uses precise measurements of ultrasonic wave speeds to determine the elastic constants. From these, the more familiar engineering constants were derived. This report is divided into four sections: **Summary with Load Dependence Data, Velocity Data for Ambient Temperature Elastic Constants, and Elevated Temperature Data.**

Summary of Test Results

Samples

ABC Friction Material

Three disc type brake pads were received for this analysis. Two test samples were extracted from each and they were labeled as follows:

From one brake pad two test samples were prepared: a rectangular piece labeled ABC_A and a 45 degree cut labeled ABC_A_45a.

From the second brake pad two test samples were prepared: a rectangular piece labeled ABC_B and a 45 degree cut labeled ABC_B_45a.

From the third brake pad two test samples were prepared: a rectangular piece labeled ABC_C and a 45 degree cut labeled ABC_C_45a.

Table 1 shows the summary results from the measurements of five different ultrasonic modes on the three different test samples. All results are referenced to the coordinate system shown in Figure 1. The Table shows the average and the standard deviations for all measured modes. We have combined the measurements of modes V_{11} and V_{22} as well as the modes V_{32} and V_{31}. The observations, $V_{11} \sim V_{22}$ and $V_{31} \sim V_{32}$, indicate that the material is transversely isotropic. The properties along the "1=x" and "2=y" axes are nearly identical and the unique axis is oriented out of the plane of the pad ("3=z").

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Table 1 Ultrasonic Velocities for Seven Modes

Velocity Data Summary						
Sample ID	**V_{33}**	**$<V_{22};V_{11}>$**	**$<V_{31};V_{32}>$**	**V_{21}**	**V_{45}**	**Density**
	(km/s)	**(km/s)**	**(km/s)**	**(km/s)**	**(km/s)**	**(g/cm^3)**
Sample ABC_A	1.096	2.479	0.985	1.526	0.924	2.856
Sample ABC_B	1.125	2.410	0.987	1.528	0.945	2.844
Sample ABC_C	1.205	2.573	1.066	1.615	0.940	2.913
Average	**1.142**	**2.487**	**1.013**	**1.556**	**0.936**	**2.871**
% STDEV	**4.95**	**3.28**	**4.56**	**3.25**	**1.18**	**1.28**

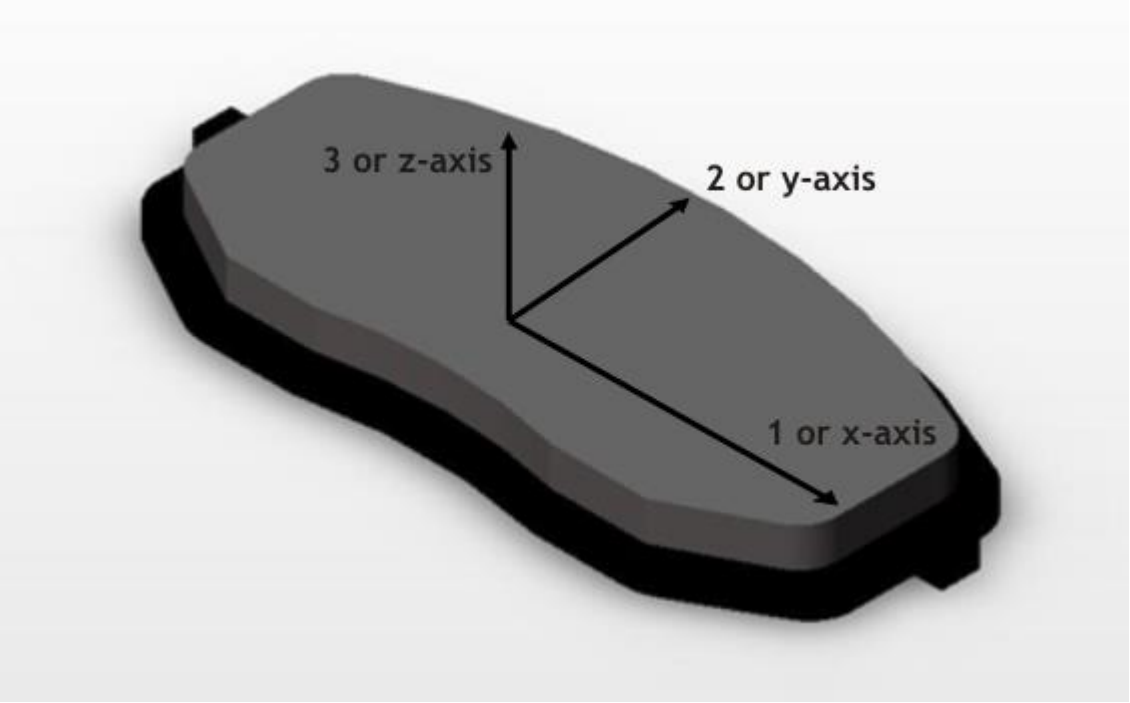

Figure 1 Coordinate Definition

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The average values shown in Table 1 are used to compute the elastic and engineering constants for the **ABC** friction material. These results are presented below in Table 2.

Table 2 Average Engineering Constants & Elastic Constants for ABC

Ultrasound Velocity							
V_{33}	$<V_{22};V_{11}>$	$<V_{31};V_{32}>$	V_{12}	□	V_{45}		
(km/s)	(km/s)	(km/s)	(km/s)	(g/cm^3)	(km/s)		
1.142	2.487	1.013	1.556	2.871	0.936		
Elastic Constants							
C_{11}	C_{22}	C_{33}	C_{44}	C_{55}	C_{66}	C_{12}	C_{13}
(GPa)	(GPa)	(GPa)	(GPa)	(GPa)	(GPa)	(GPa)	(GPa)
17.76	17.76	3.74	2.94	2.94	6.96	3.85	2.15
Engineering Constants							
	(GPa)	(ksi)					
$E_x=E_y$	16.07	2330	Young's Modulus (in-Plane)				
$V_{12}=V_{21}$	0.16	0.16	Poisson's Ratio				
$E_z=E_3$	3.30	478	Young's Modulus (out-of-Plane)				
$V_{31}=V_{32}$	0.10	0.10	Poisson's Ratio				
$V_{23}=V_{13}$	0.48	0.48	Poisson's Ratio				
$G_{13}=G_{23}$	2.95	428	Shear Modulus				
G_{12}	6.96	1010	Shear Modulus				

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Table 3 Load Dependence Data

	%Modulus Change C_{33}							%Modulus Change C_{44}						
Pressure (MPa)	ABC_A	ABC_B	ABC_C	Avg.	St. Dev.	Avg. + Std.	Avg. - Std.	ABC_A	ABC_B	ABC_C	Avg.	St. Dev.	Avg. + Std.	Avg. - Std.
5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	-0.49	0.73	0.00	0.08	0.61	0.69	-0.53	-0.64	-0.62	-0.69	-0.65	0.04	-0.62	-0.69
4.5	-2.63	0.97	-0.79	-0.82	1.80	0.98	-2.62	-1.49	-1.04	-1.38	-1.30	0.24	-1.07	-1.54
4.0	-2.63	1.22	-1.06	-0.82	1.93	1.11	-2.76	-2.95	-2.66	-2.06	-2.56	0.45	-2.11	-3.01
3.5	-3.10	1.22	-1.06	-0.98	2.16	1.18	-3.14	-4.38	-3.66	-2.51	-3.52	0.94	-2.58	-4.46
3.0	-3.33	1.71	-1.58	-1.07	2.56	1.49	-3.62	-5.38	-5.22	-3.18	-4.59	1.23	-3.37	-5.82
2.4	-4.02	2.20	-3.37	-1.73	3.42	1.69	-5.15	-6.37	-6.37	-3.62	-5.45	1.58	-3.87	-7.04
2.0	-4.71	2.45	-5.36	-2.54	4.33	1.80	-6.87	-7.53	-6.56	-3.62	-5.90	2.03	-3.87	-7.94
1.5	-5.61	2.20	-9.85	-4.42	6.11	1.70	-10.53	-8.10	-7.49	-3.40	-6.33	2.56	-3.78	-8.89
1.0	-7.37	-1.90	-14.02	-7.76	6.07	-1.69	-13.83	-8.86	-8.42	-4.06	-7.11	2.65	-4.46	-9.76
0.5	-12.97	-8.98	-17.32	-13.09	4.17	-8.92	-17.26	-9.60	-8.42	-3.84	-7.29	3.04	-4.25	-10.33

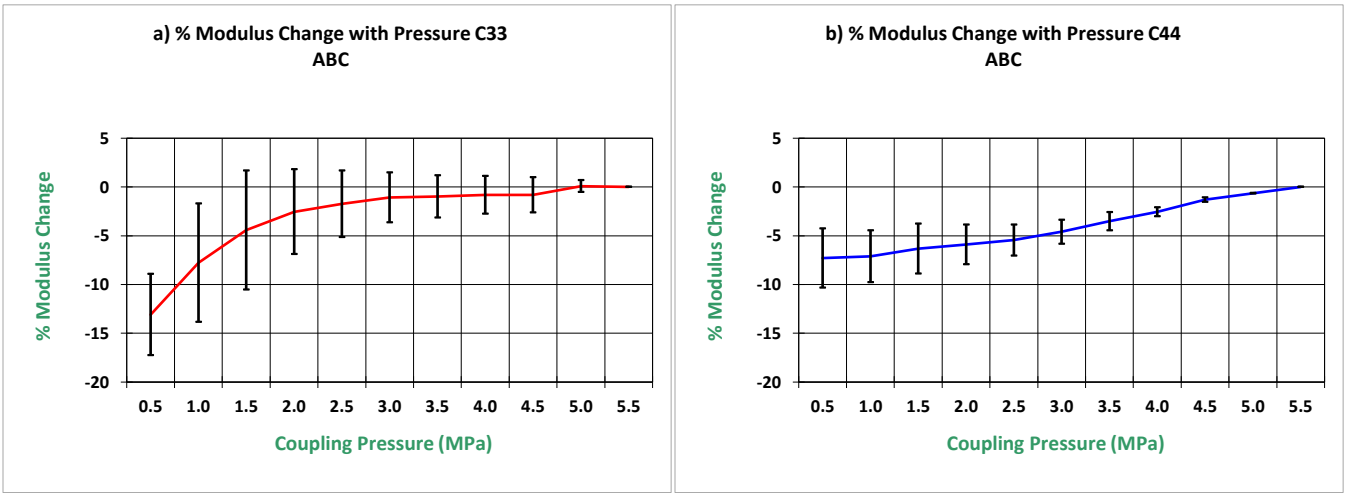

Figure 2 Graphs of the average change in modulus as a function of coupling pressure for C_{33} and C_{44}

The load sensitivity of the C_{33} and C_{44} elastic constants are plotted in Figure 2a and 2b and presented in tabular form in Table 3 for the Type ABC material. The load dependence of the through-the-thickness modes (V_{33} and V_{32}) are measured by monitoring the variation in ultrasonic transit time as the load is applied. Many friction materials exhibit a modulus which is load-dependent in the thickness direction. Variation in modulus over the coupling pressure range from 0.5 MPa to 6 MPa is a measure of the material non-linearity. For some materials, variations as high as 50 percent have been observed.

The ABC material would be classified as having moderate load dependence for both the shear and longitudinal modulus. The data in Figure 2 show the % variation in modulus from the maximum value measured at the highest load. The plotted points are the average values obtained from three samples and the error bars are the standard deviations. Two features should be noted: 1) modulus generally increases with increasing load and 2) measurement variability increases with decreasing load. For both the shear wave measurements, C_{44} and longitudinal measurements, C_{33}, there is some evidence of a plateau at the higher loads.

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Ambient Temperature Velocity Data for Elastic Constants

(Results for individual samples)

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Ambient Temperature Velocity Data

From the brakes in as-received condition, smaller, 15 mm by 20 mm by ~9 mm rectangular test specimens were cut. The longest sample dimension, (20 mm), corresponds to the longest dimension of the original pad ("1=x" direction in our defined coordinate system). The 9 mm dimension always corresponds to the thickness dimension ("3=z" direction in our defined coordinate system). From these samples, all of the diagonal elements of the elastic constant matrix and one off-diagonal element can be determined. One rectangular piece was taken from each pad.

A second sample type, cut 45° relative to the thickness direction, was used to obtain one of the off-diagonal elements to the elastic constant matrix. This sample was cut from a sample section directly adjacent to the rectangular pieces. Only one 45-degree piece was extracted from the pad.

Sample density is determined by dividing the weight of the sample by the measured volume. The dimensions of each rectangular piece are measured with a micrometer. Each sample is weighed using a scale with a precision of .01 grams.

In some friction materials the attenuation (signal loss) in the V_{33} mode is very high (in excess of 70 dB). The wave shape may be distorted and materials are non-linear (velocity varies with load). We find that the signal level and wave shape distortion can be improved if measurements are made under load. For this mode, as well as the V_{31} and V_{32} mode, we use ~700 Newtons (160 lbs), of force to couple the transducers. Because the contact area is approximately 1.71 square centimeters, this force translates to a pressure of 4.1 MPa (600 psi).

The elastic constant data contained in this report used methods described in preliminary Specification SAE J2725 at a coupling pressure of ~4 MPa. For the in-plane modes, neither wave shape nor measured transit time appear to be load sensitive. However, for consistency, we use a coupling force which leads to a pressure of ~4 MPa (600 psi) for the samples in this orientation.

The definition of the terminology used to identify the ultrasonic modes is given below:

V_{33} - Longitudinal mode propagating along the "3=z" direction
V_{11} - Longitudinal mode propagating along the "1=x" direction
V_{22} - Longitudinal mode propagating along the "2=y" direction
V_{31} - Shear mode propagating along the "3=z" direction polarized along the "1=x" direction
V_{32} - Shear mode propagating along the "3=z" direction polarized along the "2=y" direction
V_{21} - Shear mode propagating along the "2=y" direction polarized along the "1=x" direction
V_{12} - Shear mode propagating along the "1=x" direction polarized along the "2=y" direction

Along with all of the ultrasonic data, the modulus calculations on each individual piece are given in the following pages.

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Sample ABC_A

Mode	Corrected Transit Time (us)	Load (N)	Coupling Pressure (MPa)	Thickness (mm)	Velocity (km/s)
v33	8.460	697	4.03	9.33	1.103
v33	8.500	700	4.05	9.33	1.098
v33	8.550	698	4.03	9.33	1.091
v33	8.550	694	4.01	9.33	1.091
v22	5.850	517	4.00	14.38	2.458
v22	5.770	519	4.01	14.38	2.492
v22	5.770	521	4.03	14.38	2.492
v11	7.430	541	4.03	18.50	2.490
v11	7.480	544	4.05	18.50	2.473
v11	7.500	541	4.03	18.50	2.467
v32	9.570	699	4.04	9.33	0.975
v32	9.640	698	4.03	9.33	0.968
v32	9.620	699	4.04	9.33	0.970
v31	9.350	696	4.02	9.33	0.998
v31	9.330	697	4.03	9.33	1.000
v31	9.360	696	4.02	9.33	0.997
v21	9.410	518	4.01	14.38	1.528
v21	9.450	517	4.00	14.38	1.522
v21	9.410	518	4.01	14.38	1.528
v45	5.150	540	4.02	4.66	0.905
v45	5.140	537	4.00	4.66	0.907
v45	4.860	537	4.00	4.66	0.959
v45	5.040	540	4.02	4.66	0.925

Velocity Data Summary						
	V_{33} (km/s)	**$\langle V_{22};V_{11}\rangle$ (km/s)**	**$\langle V_{31};V_{32}\rangle$ (km/s)**	**V_{21} (km/s)**	**V_{45} (km/s)**	**Density (g/cm^3)**
Avg Velocity	1.096	2.479	0.984	1.526	0.924	2.856
# of Reps	4	6	6	3	4	
% Std Dev	0.513	0.638	0.270	0.245	2.712	

Elastic Constants						
	$\langle C_{11};C_{22}\rangle$	**C_{33}**	**$\langle C_{44};C_{55}\rangle$**	**C_{66}**	**C_{12}**	**C_{13}**
GPa	17.55	3.43	2.77	6.65	4.25	1.75

Engineering Constants							
	Young's Modulus			**Shear Modulus**		**Poisson's Ratio**	
	GPa	**ksi**		**GPa**	**ksi**	**$V_{12}=V_{21}$**	0.20
In-plane ($E_x=E_y$)	15.98	2317.79	**$G_{13}=G_{23}$**	2.77	401.59	**$V_{31}=V_{32}$**	0.08
Out-of-plane ($E_Z=E_3$)	3.15	456.54	**G_{12}**	6.65	964.78	**$V_{23}=V_{13}$**	0.41

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Sample ABC_B

Mode	Corrected Transit Time (us)	Load (N)	Coupling Pressure (MPa)	Thickness (mm)	Velocity (km/s)
v33	8.580	694	3.98	9.57	1.115
v33	8.560	708	4.06	9.57	1.118
v33	8.420	699	4.01	9.57	1.137
v33	8.480	703	4.04	9.57	1.129
v22	6.150	530	4.01	14.76	2.400
v22	6.190	531	4.02	14.76	2.384
v22	6.210	528	4.00	14.76	2.377
v11	7.710	568	4.02	18.67	2.422
v11	7.670	566	4.01	18.67	2.434
v11	7.640	567	4.01	18.67	2.444
v32	9.810	701	4.02	9.57	0.976
v32	9.840	697	4.00	9.57	0.973
v32	9.800	698	4.01	9.57	0.977
v31	9.560	700	4.02	9.57	1.001
v31	9.530	704	4.04	9.57	1.004
v31	9.620	698	4.01	9.57	0.995
v21	9.660	532	4.03	14.76	1.528
v21	9.660	531	4.02	14.76	1.528
v21	9.650	529	4.01	14.76	1.530
v45	4.640	562	3.98	4.30	0.927
v45	4.520	562	3.98	4.30	0.951
v45	4.470	566	4.01	4.30	0.962
v45	4.580	564	3.99	4.30	0.939

Velocity Data Summary						
	V_{33} (km/s)	$\langle V_{22};V_{11}\rangle$ (km/s)	$\langle V_{31};V_{32}\rangle$ (km/s)	V_{21} (km/s)	V_{45} (km/s)	Density (g/cm^3)
Avg Velocity	1.125	2.410	0.988	1.528	0.945	2.844
# of Reps	4	6	6	3	4	
% Std Dev	0.871	0.476	0.345	0.060	1.616	

Elastic Constants						
	$\langle C_{11};C_{22}\rangle$	C_{33}	$\langle C_{44};C_{55}\rangle$	C_{66}	C_{12}	C_{13}
GPa	16.52	3.60	2.77	6.64	3.23	1.52

Engineering Constants							
	Young's Modulus			**Shear Modulus**		**Poisson's Ratio**	
	GPa	**ksi**		**GPa**	**ksi**	$V_{12}=V_{21}$	0.16
In-plane ($E_x=E_y$)	15.46	2241.97	$G_{13}=G_{23}$	2.77	402.19	$V_{31}=V_{32}$	0.08
Out-of-plane ($E_Z=E_3$)	3.36	487.97	G_{12}	6.64	963.65	$V_{23}=V_{13}$	0.35

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Sample ABC_C

Mode	Corrected Transit Time (us)	Load (N)	Coupling Pressure (MPa)	Thickness (mm)	Velocity (km/s)
v33	7.740	697	4.00	9.30	1.202
v33	7.770	703	4.04	9.30	1.197
v33	7.640	701	4.02	9.30	1.217
v33	7.730	701	4.02	9.30	1.203
v22	5.810	518	4.02	14.77	2.542
v22	5.830	519	4.02	14.77	2.533
v22	5.840	517	4.01	14.77	2.529
v11	7.130	551	4.01	18.57	2.604
v11	7.130	548	3.99	18.57	2.604
v11	7.080	551	4.01	18.57	2.623
v32	8.830	699	4.01	9.30	1.053
v32	8.880	703	4.04	9.30	1.047
v32	8.880	699	4.01	9.30	1.047
v31	8.590	703	4.04	9.30	1.083
v31	8.570	700	4.02	9.30	1.085
v31	8.610	697	4.00	9.30	1.080
v21	9.130	518	4.02	14.77	1.618
v21	9.170	513	3.98	14.77	1.611
v21	9.140	517	4.01	14.77	1.616
v45	4.640	551	4.01	4.33	0.933
v45	4.580	551	4.01	4.33	0.945
v45	4.450	551	4.01	4.33	0.973
v45	4.760	545	3.97	4.33	0.910

Velocity Data Summary						
	V_{33} (km/s)	$\langle V_{22};V_{11}\rangle$ (km/s)	$\langle V_{31};V_{32}\rangle$ (km/s)	V_{21} (km/s)	V_{45} (km/s)	Density (g/cm^3)
Avg Velocity	1.205	2.573	1.066	1.615	0.940	2.913
# of Reps	4	6	6	3	4	
% Std Dev	0.729	0.335	0.280	0.227	2.805	

Elastic Constants						
	$\langle C_{11};C_{22}\rangle$	C_{33}	$\langle C_{44};C_{55}\rangle$	C_{66}	C_{12}	C_{13}
GPa	19.28	4.23	3.31	7.60	4.09	3.14

Engineering Constants							
	Young's Modulus			Shear Modulus		Poisson's Ratio	
	GPa	ksi		GPa	ksi	$V_{12}=V_{21}$	0.10
In-plane ($E_x=E_y$)	16.76	2431.51	$G_{13}=G_{23}$	3.31	480.04	$V_{31}=V_{32}$	0.13
Out-of-plane ($E_Z=E_3$)	3.38	490.69	G_{12}	7.60	1101.62	$V_{23}=V_{13}$	0.67

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Elevated Temperature Data

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Elevated Temperature Measurements

The same samples measured at ambient temperature are used for the elevated temperature measurements. For each material type, only the four unique modes are measured at elevated temperature: V_{33}, ($V_{32} = V_{31}$), ($V_{21} = V_{12}$), and ($V_{11} = V_{22}$). These measurements yield the diagonal elements of the elastic constant matrix C_{33}, $C_{44} = C_{55}$, C_{66}, and $C_{11} = C_{22}$, respectively. This data is presented in both tabular and graphical form in this section. The off diagonal element, C_{12}, is related to the diagonal elements and this relation is given directly by $C_{12} = C_{22} - 2*C_{66}$. The other off-diagonal element's temperature dependence, (C_{13}), is best estimated by assuming that it is similar to that of C_{12}.

The attenuation data is also presented. Particular care should be exercised in trying to interpret the attenuation data for shear wave measurement modes e.g. $C_{44} = C_{55}$, and C_{66}, since the coupling at the interface between the sample and transducer exhibits some thermal instability. The coupling layer is too thin to influence the velocity data. However, it does impact the attenuation data at elevated temperatures. This is less of a problem for the longitudinal waves (C_{33}, and $C_{11} = C_{22}$) where ultrasonic coupling and intrinsic sample attenuation appear to be more stable with temperature.

For the elevated temperature data, the velocities measured on each sample at ambient temperature are used to normalize the data. A heating profile involves heating the samples in a stepwise fashion at 50-degree Centigrade increments from ambient to 325°C. At each interval, a holding time of 5 minutes is used to allow the sample to equilibrate before the velocity measurement is made. For a typical high temperature analysis, only the four diagonal elements of the elastic constant matrix are measured. Generally each mode is analyzed only once.

Specific temperature dependent data is plotted for each diagonal element of the three samples analyzed. The temperature dependence for C_{12} must be calculated. Similarly, the C_{13} temperature dependence is assumed to parallel that of C_{12}.

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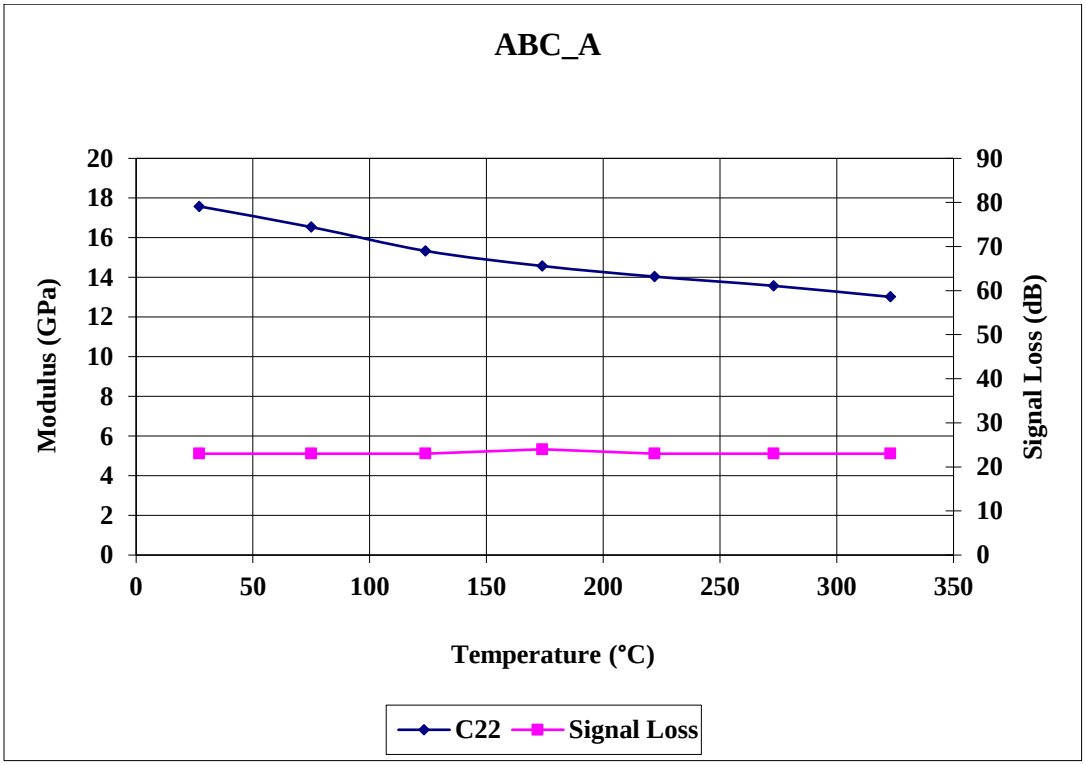
ABC_A				
Elevated Temperature Data for Mode v22(C22)				
Temp (°C)	Corrected Transit Time (us)	Velocity (km/s)	Elastic Constants	Signal Loss (dB)
27	5.797	2.481	17.579	23
75	5.977	2.406	16.536	23
124	6.207	2.317	15.333	23
174	6.367	2.259	14.572	24
222	6.487	2.217	14.038	23
273	6.597	2.180	13.574	23
323	6.737	2.135	13.016	23



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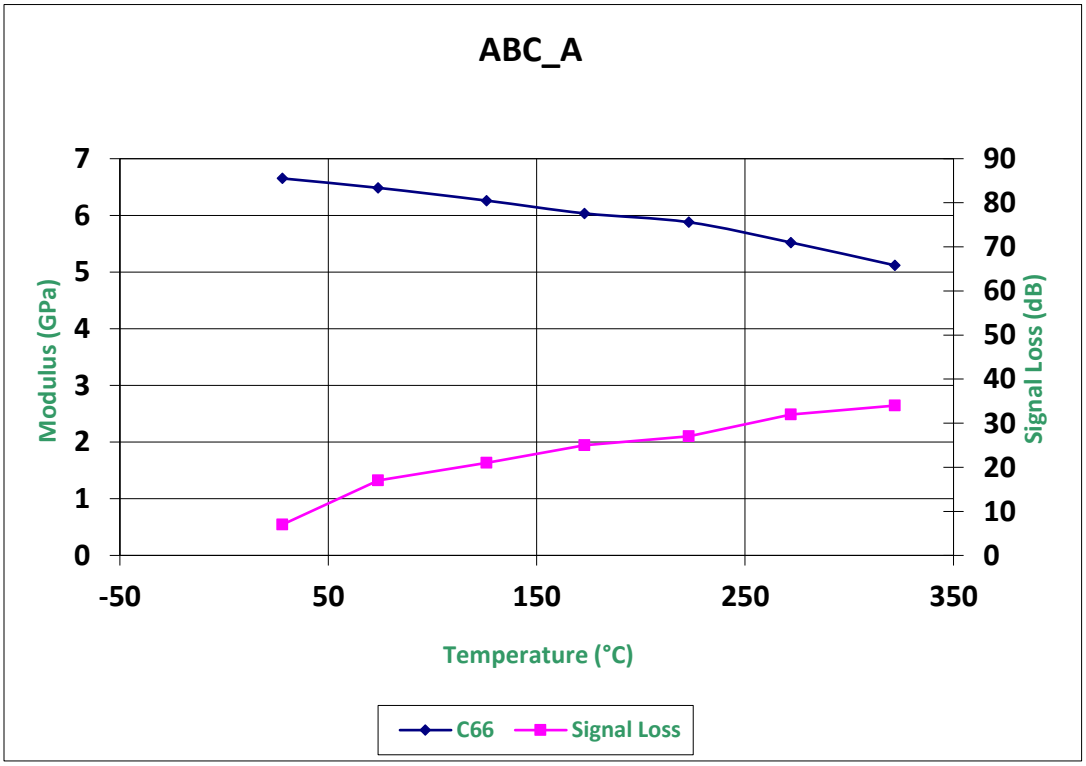
ABC_A				
Elevated Temperature Data for Mode v21(C66)				
Temp (°C)	Corrected Transit Time (us)	Velocity (km/s)	Elastic Constants	Signal Loss (dB)
28	9.423	1.526	6.652	7
74	9.543	1.507	6.486	17
126	9.713	1.480	6.261	21
173	9.893	1.454	6.035	25
223	10.023	1.435	5.879	27
272	10.343	1.390	5.521	32
322	10.743	1.339	5.118	34



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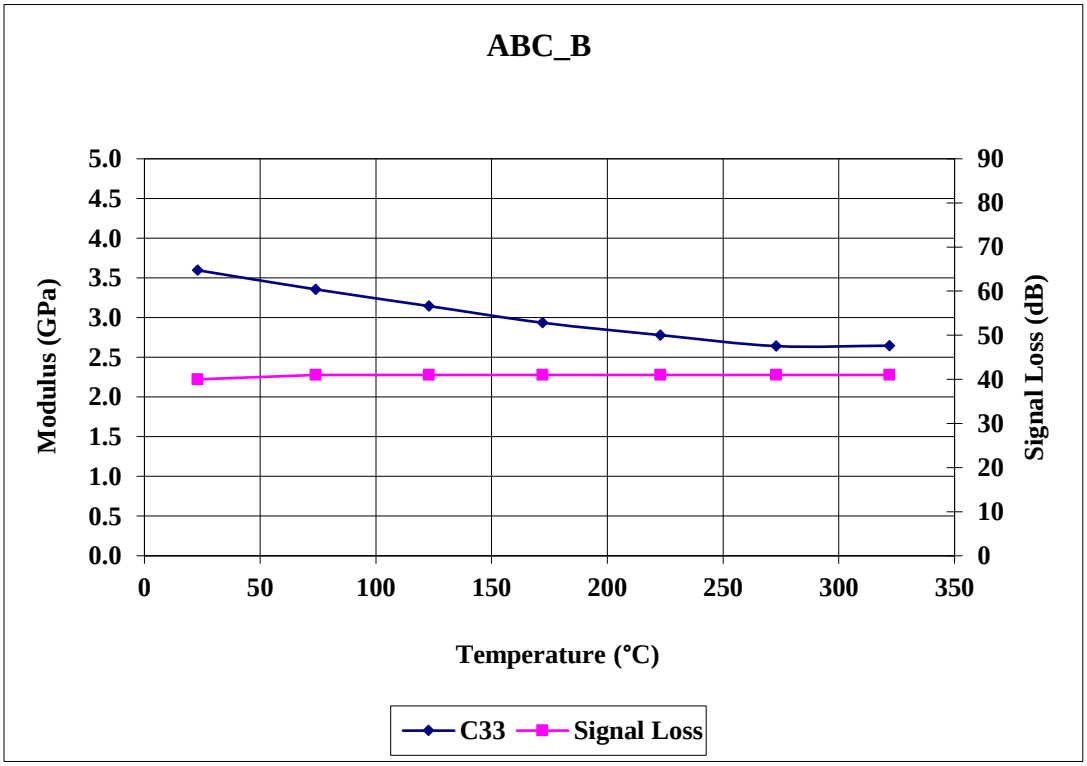
ABC_B				
Elevated Temperature Data for Mode v33(C33)				
Temp (°C)	Corrected Transit Time (us)	Velocity (km/s)	Elastic Constants	Signal Loss (dB)
23	8.510	1.125	3.597	40
74	8.810	1.086	3.356	41
123	9.100	1.052	3.145	41
172	9.420	1.016	2.935	41
223	9.680	0.989	2.780	41
273	9.930	0.964	2.641	41
322	9.920	0.965	2.647	41



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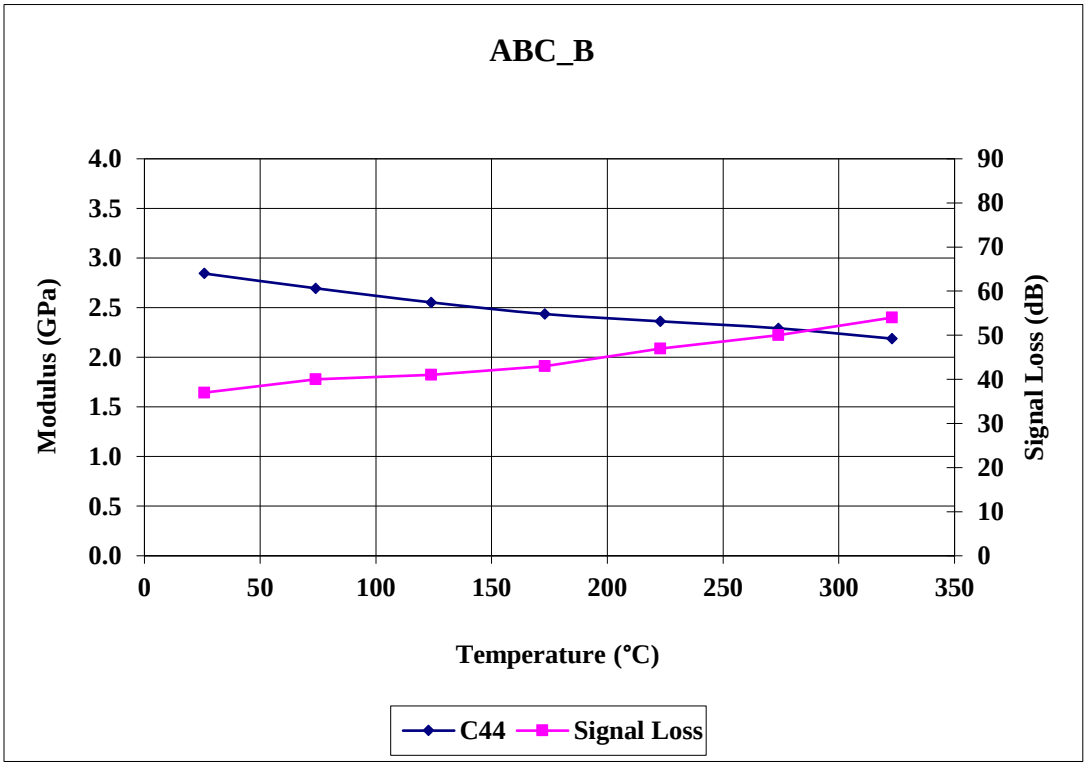
ABC_B				
Elevated Temperature Data for Mode v31(C44)				
Temp (°C)	Corrected Transit Time (us)	Velocity (km/s)	Elastic Constants	Signal Loss (dB)
26	9.570	1.000	2.844	37
74	9.830	0.974	2.695	40
124	10.100	0.948	2.553	41
173	10.340	0.926	2.436	43
223	10.500	0.911	2.362	47
274	10.660	0.898	2.292	50
323	10.910	0.877	2.188	54



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Enhanced Data

Condition - Temperature and Pressure (˚C X Bar)	Longitudinal Modulus (GPa)		Shear Modulus (GPa)		Poisson's Ratio		
	In plane	Out plane	In plane	Out plane	v12=v21	v31=v32	v23=v13
Ambient X 5	16.51	3.10	6.96	2.80	0.19	0.07	0.36
Ambient X 10	16.41	3.16	6.96	2.82	0.18	0.08	0.40
Ambient X 15	16.32	3.20	6.96	2.83	0.17	0.08	0.43
Ambient X 20	16.24	3.24	6.96	2.85	0.17	0.09	0.45
Ambient X 25	16.19	3.27	6.96	2.87	0.16	0.09	0.47
Ambient X 30	16.14	3.29	6.96	2.89	0.16	0.10	0.48
Ambient X 35	16.12	3.31	6.96	2.92	0.16	0.10	0.48
Ambient X 40	16.12	3.32	6.96	2.94	0.16	0.10	0.48
Ambient X 45	16.13	3.32	6.96	2.97	0.16	0.10	0.48
Ambient X 50	16.16	3.32	6.96	3.00	0.16	0.10	0.47
Ambient X 55	16.20	3.31	6.96	3.04	0.16	0.09	0.46
Ambient X 30	16.14	3.29	6.96	2.89	0.16	0.10	0.48
75 X 30	15.49	3.14	6.81	2.74	0.14	0.08	0.42
125 X 30	15.15	3.07	6.72	2.68	0.13	0.08	0.39
175 X 30	14.81	2.99	6.61	2.61	0.12	0.07	0.37
225 X 30	14.15	2.85	6.37	2.49	0.11	0.07	0.33
275 X 30	13.83	2.78	6.23	2.44	0.11	0.07	0.33
325 X 30	13.52	2.72	6.08	2.40	0.11	0.07	0.33

Condition - Temperature and Pressure (° C X Bar)	Longitudinal Modulus (GPa)		Shear Modulus (GPa)		Poisson's Ratio		
	In plane	Out plane	In plane	Out plane	v12=v21	v31=v32	v23=v13
20 X 5	16.51	3.10	6.96	2.80	0.19	0.07	0.36
20 X 15	16.41	3.16	6.96	2.82	0.18	0.08	0.40
20 X 30	16.32	3.20	6.96	2.83	0.17	0.08	0.43
100 X 5	15.46	2.87	6.72	2.59	0.15	0.05	0.25
100 X 15	15.30	2.98	6.72	2.62	0.14	0.06	0.33
100 X 30	15.15	3.07	6.72	2.68	0.13	0.08	0.39
200 X 5	14.06	2.58	6.23	2.37	0.13	0.03	0.17
200 X 15	13.95	2.69	6.23	2.39	0.12	0.05	0.26
200 X 30	13.83	2.78	6.23	2.44	0.11	0.07	0.33
300 X 5	12.87	2.37	5.57	2.21	0.16	0.04	0.23
300 X 15	12.75	2.46	5.57	2.23	0.15	0.06	0.31
300 X 30	12.63	2.54	5.57	2.28	0.13	0.07	0.37

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IMS Pressure Dependence at @ RT (ambient)

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
26	0.5	2.87	1.072	2.487	0.988	1.556	0.927	16.51	3.10	6.96	2.80	0.19	0.07	0.36	17.76	3.30	2.80	6.96	3.85	1.46
26	1.0	2.87	1.090	2.487	0.991	1.556	0.928	16.41	3.16	6.96	2.82	0.18	0.08	0.40	17.76	3.41	2.82	6.96	3.85	1.66
26	1.5	2.87	1.105	2.487	0.993	1.556	0.929	16.32	3.20	6.96	2.83	0.17	0.08	0.43	17.76	3.51	2.83	6.96	3.85	1.81
26	2.0	2.87	1.117	2.487	0.997	1.556	0.930	16.24	3.24	6.96	2.85	0.17	0.09	0.45	17.76	3.58	2.85	6.96	3.85	1.94
26	2.5	2.87	1.127	2.487	1.000	1.556	0.932	16.19	3.27	6.96	2.87	0.16	0.09	0.47	17.76	3.65	2.87	6.96	3.85	2.03
26	3.0	2.87	1.135	2.487	1.004	1.556	0.933	16.14	3.29	6.96	2.89	0.16	0.10	0.48	17.76	3.70	2.89	6.96	3.85	2.10
26	3.5	2.87	1.139	2.487	1.008	1.556	0.935	16.12	3.31	6.96	2.92	0.16	0.10	0.48	17.76	3.73	2.92	6.96	3.85	2.13
26	4.0	2.87	1.142	2.487	1.013	1.556	0.936	16.12	3.32	6.96	2.94	0.16	0.10	0.48	17.76	3.74	2.94	6.96	3.85	2.15
26	4.5	2.87	1.141	2.487	1.018	1.556	0.938	16.13	3.32	6.96	2.97	0.16	0.10	0.48	17.76	3.74	2.97	6.96	3.85	2.13
26	5.0	2.87	1.138	2.487	1.023	1.556	0.940	16.16	3.32	6.96	3.00	0.16	0.10	0.47	17.76	3.72	3.00	6.96	3.85	2.09
26	5.5	2.87	1.133	2.487	1.029	1.556	0.942	16.20	3.31	6.96	3.04	0.16	0.09	0.46	17.76	3.69	3.04	6.96	3.85	2.02

IMS Temperature Dependence at @ 30 bar (3 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
26	3.02	2.87	1.135	2.487	1.004	1.556	0.933	16.14	3.29	6.96	2.89	0.16	0.10	0.48	17.76	3.70	2.89	6.96	3.85	2.10
25	3.00	2.87	1.136	2.490	1.005	1.557	0.933	16.16	3.29	6.96	2.90	0.16	0.10	0.48	17.80	3.70	2.90	6.96	3.88	2.11
75	3.00	2.87	1.092	2.404	0.978	1.540	0.918	15.49	3.14	6.81	2.74	0.14	0.08	0.42	16.59	3.42	2.74	6.81	2.97	1.65
100	3.00	2.87	1.072	2.365	0.965	1.530	0.909	15.15	3.07	6.72	2.68	0.13	0.08	0.39	16.06	3.30	2.68	6.72	2.63	1.47
125	3.00	2.87	1.054	2.330	0.954	1.518	0.900	14.81	2.99	6.61	2.61	0.12	0.07	0.37	15.58	3.19	2.61	6.61	2.36	1.33
175	3.00	2.87	1.023	2.266	0.932	1.489	0.882	14.15	2.85	6.37	2.49	0.11	0.07	0.33	14.75	3.00	2.49	6.37	2.01	1.13
200	3.00	2.87	1.010	2.239	0.922	1.473	0.873	13.83	2.78	6.23	2.44	0.11	0.07	0.33	14.39	2.93	2.44	6.23	1.94	1.08
225	3.00	2.87	0.998	2.214	0.913	1.455	0.863	13.52	2.72	6.08	2.40	0.11	0.07	0.33	14.08	2.86	2.40	6.08	1.93	1.06
275	3.00	2.87	0.979	2.174	0.898	1.415	0.843	12.92	2.60	5.75	2.31	0.12	0.07	0.35	13.57	2.75	2.31	5.75	2.07	1.10
300	3.00	2.87	0.972	2.158	0.891	1.393	0.832	12.63	2.54	5.57	2.28	0.13	0.07	0.37	13.37	2.71	2.28	5.57	2.23	1.16
325	3.00	2.87	0.967	2.144	0.884	1.369	0.821	12.34	2.48	5.38	2.25	0.15	0.08	0.40	13.20	2.68	2.25	5.38	2.44	1.25

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IMS Temperature Dependence at @ 15 bar (1.5 Mpa)

								Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45	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
26	1.51	2.87	1.105	2.487	0.993	1.556	0.929	16.32	3.20	6.96	2.83	0.17	0.08	0.43	17.76	3.51	2.83	6.96	3.85	1.81
25	1.50	2.87	1.106	2.490	0.994	1.557	0.930	16.34	3.20	6.96	2.84	0.17	0.08	0.43	17.80	3.51	2.84	6.96	3.88	1.82
75	1.50	2.87	1.063	2.404	0.967	1.540	0.914	15.65	3.05	6.81	2.69	0.15	0.07	0.36	16.59	3.25	2.69	6.81	2.97	1.37
100	1.50	2.87	1.044	2.365	0.955	1.530	0.905	15.30	2.98	6.72	2.62	0.14	0.06	0.33	16.06	3.13	2.62	6.72	2.63	1.20
125	1.50	2.87	1.026	2.330	0.944	1.518	0.897	14.95	2.90	6.61	2.56	0.13	0.06	0.30	15.58	3.03	2.56	6.61	2.36	1.05
175	1.50	2.87	0.996	2.266	0.922	1.489	0.879	14.27	2.76	6.37	2.44	0.12	0.05	0.27	14.75	2.85	2.44	6.37	2.01	0.87
200	1.50	2.87	0.983	2.239	0.913	1.473	0.869	13.95	2.69	6.23	2.39	0.12	0.05	0.26	14.39	2.77	2.39	6.23	1.94	0.82
225	1.50	2.87	0.972	2.214	0.904	1.455	0.859	13.63	2.63	6.08	2.35	0.12	0.05	0.26	14.08	2.71	2.35	6.08	1.93	0.80
275	1.50	2.87	0.953	2.174	0.888	1.415	0.839	13.04	2.51	5.75	2.26	0.13	0.06	0.29	13.57	2.61	2.26	5.75	2.07	0.86
300	1.50	2.87	0.946	2.158	0.881	1.393	0.829	12.75	2.46	5.57	2.23	0.15	0.06	0.31	13.37	2.57	2.23	5.57	2.23	0.94
325	1.50	2.87	0.941	2.144	0.875	1.369	0.818	12.46	2.41	5.38	2.20	0.16	0.07	0.34	13.20	2.54	2.20	5.38	2.44	1.03

IMS Temperature Dependence at @ 5 bar (0.5 Mpa)

								Young's Modulus		Shear Modulus		Poisson's Ratio			Elastic Constants					
Temp.	Pressure	Rho	V33	<V22;V11>	<V31;V32>	V12	V45	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
26	0.50	2.87	1.072	2.487	0.988	1.556	0.927	16.51	3.10	6.96	2.80	0.19	0.07	0.36	17.76	3.30	2.80	6.96	3.85	1.46
25	0.50	2.87	1.073	2.490	0.989	1.557	0.928	16.53	3.11	6.96	2.81	0.19	0.07	0.36	17.80	3.31	2.81	6.96	3.88	1.48
75	0.50	2.87	1.032	2.404	0.962	1.540	0.912	15.82	2.95	6.81	2.66	0.16	0.05	0.28	16.59	3.06	2.66	6.81	2.97	1.03
100	0.50	2.87	1.013	2.365	0.950	1.530	0.903	15.46	2.87	6.72	2.59	0.15	0.05	0.25	16.06	2.95	2.59	6.72	2.63	0.86
125	0.50	2.87	0.996	2.330	0.939	1.518	0.895	15.09	2.79	6.61	2.53	0.14	0.04	0.22	15.58	2.85	2.53	6.61	2.36	0.72
175	0.50	2.87	0.967	2.266	0.917	1.489	0.877	14.39	2.65	6.37	2.42	0.13	0.03	0.17	14.75	2.68	2.42	6.37	2.01	0.54
200	0.50	2.87	0.954	2.239	0.908	1.473	0.867	14.06	2.58	6.23	2.37	0.13	0.03	0.17	14.39	2.61	2.37	6.23	1.94	0.50
225	0.50	2.87	0.943	2.214	0.899	1.455	0.858	13.75	2.52	6.08	2.32	0.13	0.03	0.17	14.08	2.55	2.32	6.08	1.93	0.49
275	0.50	2.87	0.925	2.174	0.883	1.415	0.837	13.15	2.42	5.75	2.24	0.14	0.04	0.20	13.57	2.46	2.24	5.75	2.07	0.57
300	0.50	2.87	0.919	2.158	0.876	1.393	0.827	12.87	2.37	5.57	2.21	0.16	0.04	0.23	13.37	2.42	2.21	5.57	2.23	0.65
325	0.50	2.87	0.913	2.144	0.870	1.369	0.816	12.59	2.32	5.38	2.17	0.17	0.05	0.26	13.20	2.40	2.17	5.38	2.44	0.76

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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
26	5	2.87	1.072	2.487	0.988	1.556	0.927	16.51	3.10	6.96	2.80	0.19	0.07	0.36	17.76	3.30	2.80	6.96	3.85	1.46
26	10	2.87	1.090	2.487	0.991	1.556	0.928	16.41	3.16	6.96	2.82	0.18	0.08	0.40	17.76	3.41	2.82	6.96	3.85	1.66
26	15	2.87	1.105	2.487	0.993	1.556	0.929	16.32	3.20	6.96	2.83	0.17	0.08	0.43	17.76	3.51	2.83	6.96	3.85	1.81
26	20	2.87	1.117	2.487	0.997	1.556	0.930	16.24	3.24	6.96	2.85	0.17	0.09	0.45	17.76	3.58	2.85	6.96	3.85	1.94
26	25	2.87	1.127	2.487	1.000	1.556	0.932	16.19	3.27	6.96	2.87	0.16	0.09	0.47	17.76	3.65	2.87	6.96	3.85	2.03
26	30	2.87	1.135	2.487	1.004	1.556	0.933	16.14	3.29	6.96	2.89	0.16	0.10	0.48	17.76	3.70	2.89	6.96	3.85	2.10
26	35	2.87	1.139	2.487	1.008	1.556	0.935	16.12	3.31	6.96	2.92	0.16	0.10	0.48	17.76	3.73	2.92	6.96	3.85	2.13
26	40	2.87	1.142	2.487	1.013	1.556	0.936	16.12	3.32	6.96	2.94	0.16	0.10	0.48	17.76	3.74	2.94	6.96	3.85	2.15
26	45	2.87	1.141	2.487	1.018	1.556	0.938	16.13	3.32	6.96	2.97	0.16	0.10	0.48	17.76	3.74	2.97	6.96	3.85	2.13
26	50	2.87	1.138	2.487	1.023	1.556	0.940	16.16	3.32	6.96	3.00	0.16	0.10	0.47	17.76	3.72	3.00	6.96	3.85	2.09
26	55	2.87	1.133	2.487	1.029	1.556	0.942	16.20	3.31	6.96	3.04	0.16	0.09	0.46	17.76	3.69	3.04	6.96	3.85	2.02
25	30	2.87	1.136	2.490	1.005	1.557	0.933	16.16	3.29	6.96	2.90	0.16	0.10	0.48	17.80	3.70	2.90	6.96	3.88	2.11
75	30	2.87	1.092	2.404	0.978	1.540	0.918	15.49	3.14	6.81	2.74	0.14	0.08	0.42	16.59	3.42	2.74	6.81	2.97	1.65
125	30	2.87	1.072	2.365	0.965	1.530	0.909	15.15	3.07	6.72	2.68	0.13	0.08	0.39	16.06	3.30	2.68	6.72	2.63	1.47
175	30	2.87	1.054	2.330	0.954	1.518	0.900	14.81	2.99	6.61	2.61	0.12	0.07	0.37	15.58	3.19	2.61	6.61	2.36	1.33
225	30	2.87	1.023	2.266	0.932	1.489	0.882	14.15	2.85	6.37	2.49	0.11	0.07	0.33	14.75	3.00	2.49	6.37	2.01	1.13
275	30	2.87	1.010	2.239	0.922	1.473	0.873	13.83	2.78	6.23	2.44	0.11	0.07	0.33	14.39	2.93	2.44	6.23	1.94	1.08
325	30	2.87	0.998	2.214	0.913	1.455	0.863	13.52	2.72	6.08	2.40	0.11	0.07	0.33	14.08	2.86	2.40	6.08	1.93	1.06

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	2.87	1.07	2.49	0.99	1.56	0.93	16.51	3.10	6.96	2.80	0.19	0.07	0.36	17.76	3.30	2.80	6.96	3.85	1.46
20	15	2.87	1.09	2.49	0.99	1.56	0.93	16.41	3.16	6.96	2.82	0.18	0.08	0.40	17.76	3.41	2.82	6.96	3.85	1.66
20	30	2.87	1.10	2.49	0.99	1.56	0.93	16.32	3.20	6.96	2.83	0.17	0.08	0.43	17.76	3.51	2.83	6.96	3.85	1.81
100	5	2.87	1.01	2.37	0.95	1.53	0.90	15.46	2.87	6.72	2.59	0.15	0.05	0.25	16.06	2.95	2.59	6.72	2.63	0.86
100	15	2.87	1.04	2.37	0.96	1.53	0.91	15.30	2.98	6.72	2.62	0.14	0.06	0.33	16.06	3.13	2.62	6.72	2.63	1.20
100	30	2.87	1.07	2.37	0.97	1.53	0.91	15.15	3.07	6.72	2.68	0.13	0.08	0.39	16.06	3.30	2.68	6.72	2.63	1.47
200	5	2.87	0.95	2.24	0.91	1.47	0.87	14.06	2.58	6.23	2.37	0.13	0.03	0.17	14.39	2.61	2.37	6.23	1.94	0.50
200	15	2.87	0.98	2.24	0.91	1.47	0.87	13.95	2.69	6.23	2.39	0.12	0.05	0.26	14.39	2.77	2.39	6.23	1.94	0.82
200	30	2.87	1.01	2.24	0.92	1.47	0.87	13.83	2.78	6.23	2.44	0.11	0.07	0.33	14.39	2.93	2.44	6.23	1.94	1.08
300	5	2.87	0.92	2.16	0.88	1.39	0.83	12.87	2.37	5.57	2.21	0.16	0.04	0.23	13.37	2.42	2.21	5.57	2.23	0.65
300	15	2.87	0.95	2.16	0.88	1.39	0.83	12.75	2.46	5.57	2.23	0.15	0.06	0.31	13.37	2.57	2.23	5.57	2.23	0.94
300	30	2.87	0.97	2.16	0.89	1.39	0.83	12.63	2.54	5.57	2.28	0.13	0.07	0.37	13.37	2.71	2.28	5.57	2.23	1.16

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