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ELASTIC MODULI OF BORON CARBIDE/COPPER COMPOSITES
FROM -40°C TO 800°C BY ULTRASONIC METHODS

MASTER

John H. Gieske

TRANSPORTATION TECHNOLOGY CENTER

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FROM -40°C TO 800°C BY ULTRASONIC METHODS

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ABSTRACT

An ultrasonic through-transmission technique for high attenuating materials was developed to determine the ultrasonic longitudinal and shear velocities in B_4C/Cu composites to 800°C. Ultrasonic velocity data was used to calculate Young's modulus, shear modulus, and Poisson's ratio for the composites from -40°C to 800°C.

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TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	7
II. Experimental Methods	7
Calculation of Velocities and Moduli	8
25°C Measurements	9
Low Temperature Measurements	9
Elevated Temperature Measurements	10
III. Experimental Results	13
IV. Summary and Conclusions	16
Appendix	24
References	59

LIST OF FIGURES

1. Block Diagram of Pulse-Echo-Overlap System	17
2. High Temperature Ultrasonic Travel Time Measurement System	18
3. Ultrasonic Signals for Travel Time Measurements $t_1(T)$ and $t_2(T)$ Necessary for Travel Time Calculation Through the Specimen Alone	19
4. Temperature Dependence of Young's Modulus and Shear Modulus versus B_4C/Cu Volume Percent	20
5. Temperature Dependence of Poisson's Ratio versus B_4C/Cu Volume Percent	21

TABLE

1. Ultrasonic Velocity Values Determined at 25°C for B_4C/Cu Composites	22
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I. Introduction

A materials evaluation program is being conducted for the spent fuel shipping cask of the Liquid Metal Fast Breeder Reactor (LMFBR). The mechanical properties of candidate materials must be known not only for the normal minimum and maximum working temperatures but also for extreme temperatures due to conceivable accidents. For this program current interest exists for the temperature dependence of the elastic moduli of boron carbide/copper (B_4C/Cu) composites¹. The purpose of this report is to provide Young's modulus, shear modulus, and Poisson's ratio at temperatures between $-40^\circ C$ to $800^\circ C$ as calculated from ultrasonic velocity data for the complete B_4C/Cu composite system. A description of a newly developed through-transmission technique for obtaining the temperature dependence of the ultrasonic velocity for high attenuating materials at elevated temperatures is also given.

II. Experimental Methods

The ultrasonic wave velocities were calculated for sintered powder B_4C/Cu composites of given volume fraction mixtures. Three specimens of each composition were machined from stock material to right parallelepipeds with dimensions 6.35 mm x 9.525 mm x 12.7 mm. Precise longitudinal and shear travel time measurements were made at room temperature ($25^\circ C$) in all three dimensions of one specimen and in the 12.7 mm direction of the other two specimens. Relative velocity changes from the $25^\circ C$ values were measured down to $-40^\circ C$ and up to $800^\circ C$. Measured ultrasonic travel times were made with 10 MHz longitudinal transducers and 5 MHz shear transducers for all temperature determinations.

Calculation of Velocities and Moduli

The ultrasonic velocity is simply calculated by

$$V = \frac{L}{t} \quad (1)$$

where t is the measured travel time of the ultrasonic wave through the specimen of length L . If $t(25)$ is the value of t measured at 25°C then the ultrasonic velocity at any temperature T is given by

$$V(T) = V(25) \frac{L(T)}{L(25)} \frac{t(25)}{t(T)} \quad (2)$$

or

$$V(T) = V(25) \left(1 + \frac{\Delta L(T)}{L(25)} \right) \frac{t(25)}{t(T)} \quad (3)$$

where $V(25)$ is the velocity measured at 25°C and $\frac{\Delta L(T)}{L(25)}$ is the fractional length change at temperature T due to thermal expansion.

With the calculation of the longitudinal or shear velocity at temperature T from Equation (3), the elastic moduli are calculated by the following:
Shear modulus,

$$G(T) = \rho(T) V_S^2(T); \quad (4)$$

Young's modulus,

$$E(T) = 2G(T) [1 + \sigma(T)]; \quad (5)$$

Poisson's ratio,

$$\sigma(T) = \frac{\left[1 - \frac{1}{2} \frac{V_L^2(T)}{V_S^2(T)} \right]}{1 - \frac{V_L^2(T)}{V_S^2(T)}}; \quad (6)$$

where the density $\rho(T)$ is given by

$$\rho(T) = \rho(25) \left/ \left(1 + \frac{\Delta L(T)}{L(25)} \right) \right.^3. \quad (7)$$

$V_L(T)$ is the longitudinal velocity and $V_S(T)$ is the shear velocity at temperature T .

25°C Measurements

Commercially available ultrasonic transducers were coupled directly to the faces of the specimens at 25°C with a thick resin (Dow-Corning 276-V9). A pulse-echo overlap (PEO) and a through-transmission overlap method² for the high attenuating specimens were used for the travel time measurements. A travel time correction due to transducer wear plates and coupling was applied to the measurements as described in Reference 2. The basic travel time measurements were made using a Panametrics ultrasonic time intervalometer. A block diagram of the PEO system used for the 25°C is shown in Figure 1.

Low Temperature Measurements

For the low temperature determinations the transducers were bonded to the 6.35 mm direction of the specimens with Nonaq stopcock grease (Fisher Scientific Company).

The low temperature dependence of the ultrasonic velocity was accom-

plished by placing the specimen holder and heater chamber in a liquid nitrogen Dewar. A digital low temperature indicator/controller was used to provide constant specimen temperatures from 25°C to -40°C. The temperature of the specimen was read with a chromel-alumel thermocouple in contact with the specimen. The ultrasonic travel time was measured at each temperature determination by the PEO method in the through-transmission mode using the apparatus of Figure 1. From the curve of travel time versus temperature, the ultrasonic velocity was calculated from Equation (3) down to the lowest temperature attained.

Elevated Temperature Measurements

The travel time measurements for the elevated temperatures were obtained using the apparatus shown in Figure 2. All measurements at elevated temperatures were made in the 12.7 mm dimension of the specimens. The through-transmission buffer rod arrangement shown in Figure 2 allows the transducers to remain essentially at room temperature by water cooling the ends of the buffer rods. Direct contact of the transducers with the specimen is avoided at high temperatures since the temperature of the piezoelectric must not exceed the Curie temperature.

To measure the ultrasonic travel time through the specimen alone with the through-transmission buffer rod arrangement, three separate measurements of travel time are necessary. They are, respectively, the pulse echo travel time in buffer rod #1, the pulse echo travel time in buffer rod #2, and the through-transmission travel time through buffer rod #1, the specimen, and buffer rod #2. The three position switch in Figure 2 allows each of these three modes to be displayed independently on the CRO screen.

An example of the three ultrasonic signals of interest is shown in Figure 3. From Figure 3 it is seen that the travel time $t(T)$ at temperature T through the specimen alone is obtained by

$$t(T) = t_2(T) - \frac{t_1(T)}{2} \quad (8)$$

where $t_1(T)$ is the travel time difference between the pulse echo signal from the ends of buffer rod #1 and buffer rod #2, and $t_2(T)$ is the travel time difference between the pulse echo signal from the end of buffer rod #1 and the through-transmission signal of rod #1, the specimen, and rod #2.

The apparatus of Figure 2 includes the initiation of two independently variable delay step gates which are displayed on the dual trace CRO with the ultrasonic signals. When the receiver selector switch is set for the pulse echo mode of buffer rod #1 (Position 1), the start step gate is manually set at the peak of the first half cycle echo shown in Figure 3. Then the receiver selector switch is set for the pulse echo mode of buffer rod #2 (Position 2). The stop step gate is manually set at the peak of the first half cycle echo as shown in Figure 3 and the value of $t_1(T)$ is read with the time-interval-average counter. Next the receiver selector switch is set for the through-transmission mode of buffer rod #1, the specimen, and buffer rod #2 (Position 3). The stop step gate is again manually set at the peak of the first half cycle through-transmitted signal and the value of $t_2(T)$ is read with the time-interval-average counter. The travel time through the specimen alone at temperature T is then calculated by Equation (8). The time interval average counter was read to 0.01 μ second where typical travel times through the specimen were from 2 to 10 μ seconds.

The value of $t(T)$ measured by this method at 25°C may not equal the more exact value of $t(25)$ measured with the PEO method. However the offset between these two values is expected to be constant over the temperatures measured. In this case the offset value can be subtracted from all values of $t(T)$ for a given specimen measured by the through-transmission method so that the error of $V(T)$ from Equation (3) is minimal.

The buffer rods were made of cupronickel 10 alloy*. This alloy is easily machined, has good sound transmission to at least 900°C with reproducible ultrasonic properties on increasing and decreasing temperature. The rods are approximately 270 mm long and 19 mm in diameter.

The ultrasonic couplant used between the specimen ends and buffer rods was an Indium-Gallium 50-50 by weight mixture. The Indium-Gallium mixture was rubbed onto the specimen faces and the buffer rod ends with a wooden stick until wetting of the surface occurred. The buffer rod ends were ground flat and smooth after each test to insure good wetting of the Indium-Gallium.

The buffer rod-specimen-string was spring loaded at room temperature to enhance the coupling of the ultrasound between the specimen and the buffer rods. The spring force was relieved above 600°C to prevent plastic deformation of the specimen.

The furnace was operated in the horizontal plane where one buffer rod was held fixed to the furnace stand while the other buffer rod assembly rested on a ball slide to accommodate thermal expansion of the specimen string. Alignment of the string was accomplished with the ball slide

* Cupronickel 10 is a 1.3 Fe, 10 Ni, 88.7 Cu, copper alloy and meets the specifications of copper alloy number 706 of the Copper Development Association.

mounted on a small transverse and vertical adjustment table. The table was adjusted until a maximum through-transmission signal was observed on the CRO.

To hold the buffer rod ends and specimen together inside the furnace, a small stainless steel pipe of 25 mm inner diameter was clamped to the fixed buffer rod. A chromel-alumel thermocouple was attached to the stainless steel pipe so that the bead of the thermocouple could be loaded against the specimen through a large window machined into the top of the stainless steel pipe. This arrangement allowed: easy assembly of the specimen against the buffer rod end through the window of the stainless steel pipe; loading the thermocouple against the specimen; placing the fixed buffer rod with specimen into the furnace cavity while tightening the rod to the furnace frame; inserting the other buffer rod into the other end of the furnace with self-alignment against the exposed end of the specimen after applying a spring force to hold the string together.

The ends of the furnace were packed with a high temperature fiber insulation and the furnace was purged with argon to reduce oxidation of the specimen. At least a ten minute hold at a constant temperature was realized per measurement to allow thermal equilibrium to occur in the specimen. Travel time measurements were made from room temperature to the highest temperature and then back to room temperature while always being careful to follow the same peaks of Figure 3 for each measurement of $t(T)$.

III. Experimental Results

The ultrasonic velocities determined at 25°C are listed in Table 1 for all the specimens. Velocity values for all three directions of the

specimen were measured in order to display any anisotropy present in the specimens. No significant anisotropy is present due to the sintering process; therefore, an average value of all velocity determinations of each specimen was calculated. The average values of the longitudinal and shear velocity were used to calculate the elastic moduli at 25°C for each specimen. The average values were also used in Equation (3) for the calculation of the velocities at temperature T.

The ultrasonic velocities and elastic moduli for all B_4C/Cu compositions for each temperature determination are listed in the Appendix. For each composition separate virgin specimens were used for the shear velocity determinations and the longitudinal velocity determinations. The 25°C and low temperature data were obtained before the elevated temperature data was obtained. The elevated temperature data are listed in the order in which the data were obtained. Plots of the ultrasonic velocities and normalized elastic moduli versus temperature are also shown in the Appendix for each composition. The thermal expansion data used in the calculations of Equation 3 were taken from Reference 3. Plots of Young's modulus, shear modulus, and Poisson's ratio for increasing temperatures versus B_4C/Cu compositions are also presented in Figures 4 and 5.

Both the data of increasing temperature and decreasing temperature are given in the Appendix to show the difference in measured properties due to the heat treatment. A nonlinear dependence of the elastic properties versus temperature was observed for all specimens. Specimens of 70% and 80% B_4C compositions (Samples 11, 12, 17, and 18) displayed a complex temperature dependence of the elastic properties on first heating. During cooling, the same samples displayed a more monotonic decreasing dependence of the elastic

properties versus temperature. Further for all specimens, the decreasing temperature data were more uniform than the increasing temperature data.

For all specimens heated a second time, the increasing and decreasing temperature data agreed fairly well with the decreasing temperature data on first heating; e.g., see the second heating cycle data of sample #13, 60% B_4C .

One possible explanation for the difference in properties with increasing and decreasing temperature is that the specimens undergo a volume/density change at the elevated temperatures. Evidence of the density changes was observed with the thermal expansion measurements where residual length increases were observed after cooling from the highest temperatures. The percent residual length changes observed for each composition following thermal expansion measurements³ are listed in Table 1.

These volume/density changes affected the measured moduli differently for the various compositions. On cooling, an increase in moduli was observed for the B_4C concentrations greater than 50%; whereas, a decrease in moduli was observed for the lower B_4C concentrations. As seen from the shear velocity measurements of sample 11 holding for one hour at 570°C resulted in an increase in velocity of 5.7%. Likewise for the longitudinal velocity measurements of sample 28 where the elevated temperature was held nearly constant above 747°C for one hour, resulted in an increase in velocity of 5.6%. These effects suggest that some time dependent process is taking place at elevated temperatures. The exact cause of these changes is presently unknown and is the subject of further investigation.

IV. Summary and Conclusions

Ultrasonic elastic moduli data are given from the sintered powder B_4C/Cu composite system between $-40^\circ C$ to $800^\circ C$. The elevated temperature data were obtained using a through-transmission buffer rod technique which enabled ultrasonic measurements to be made on high attenuating materials.

The moduli decreased non-linearly with temperature and displayed a marked change in temperature dependence on decreasing temperature. Specimens heated a second time repeated more nearly the temperature dependence displayed on decreasing temperature.

Figure 1 - Block Diagram of Pulse-Echo-Overlap System. The initial excitation pulse of the Panametrics unit was used as the reference signal for overlap measurements.

Figure 2 - High Temperature Ultrasonic Travel Time Measurement System

Figure 3 - Ultrasonic Signals for Travel Time Measurements $t_1(T)$ and $t_2(T)$ Necessary for Travel Time Calculation Through the Specimen Alone.

Figure 4 - Temperature Dependence of Young's Modulus and Shear Modulus versus B_4C/Cu Volume Percent

Figure 5 - Temperature Dependence of Poisson's Ratio
Versus B₄C/Cu Volume Percent

TABLE 1

Ultrasonic Velocity Values Determined at 25°C for B₄C/Cu Composites

(Data is given for three separate specimens for each composition.)

B ₄ C/Cu Composite Volume %	Specimen # and Direction in mm	Longitudinal Velocity mm/μsec	Shear Velocity mm/μsec	Density	% Length Change After Thermal Expansion Measurement
80/20	11a 6.35	6.163	3.668	3.212	----
	9.525	6.276	3.722		
	12.7	6.433	3.764		
	11b 12.7	6.612	3.882	3.310	
	11c 12.7	5.785	3.591	3.535	
	Average	6.253	3.726	3.353	
70/30	12a 6.35	6.177	3.615	4.189	+0.85
	9.525	5.872	3.613		
	12.7	6.098	3.657		
	12b 12.7	6.139	3.604	4.190	
	12c 12.7	6.149	3.611	4.289	
	Average	6.088	3.622	4.225	
60/40	13a 6.35	6.411	3.669	4.883	+1.30
	9.525	6.012	3.599		
	12.7	6.428	3.706		
	13b 12.7	6.121	3.462	5.027	
	13c 12.7	6.075	3.591	4.935	
	Average	6.207	3.606	4.948	
50/50	14a 6.35	5.918	3.470	5.132	+1.6
	9.525	5.546	3.409		
	12.7	5.906	3.489		
	14b 12.7	5.979	3.373	5.351	
	14c 12.7	5.890	3.418	5.141	
	Average	5.849	3.431	5.208	
40/60	15a 6.35	5.996	3.219	6.090	+1.8
	9.525	5.928	3.243		
	12.7	5.894	3.218		
	15b 12.7	5.857	3.163	6.479	
	15c 12.7	5.803	3.158	5.987	
	Average	5.885	3.200	6.186	

TABLE 1
(continued)

<u>B₄C/Cu Composite Volume %</u>	<u>Specimen # and Direction in mm</u>	<u>Longitudinal Velocity mm/μsec</u>	<u>Shear Velocity mm/μsec</u>	<u>Density</u>	<u>% Length Change After Thermal Expansion Measurement</u>
30/70	16a 6.35	5.447	2.895	6.644	+2.0
	9.525	5.421	2.881		
	12.7	5.442	2.892		
	16b 12.7	5.448	2.849	6.589	
	16c 12.7	5.466	2.927	6.727	
Average		5.445	2.887	6.654	
80/20 Different Powder Size Than #11	17a 6.35	6.133	3.561	3.264	+0.4
	9.525	5.842	3.486		
	12.7	6.081	3.601		
	17b 12.7	5.983	3.638	3.465	
	17c 12.7	6.370	3.643	3.172	
Average		6.080	3.586	3.301	
70/30 Different Powder Size Than #12	18a 6.35	6.135	3.661	4.037	+0.79
	9.525	5.929	3.564		
	12.7	6.226	3.639		
	18b 12.7	6.364	3.641	4.012	
	18c 12.7	6.314	3.654	4.628	
Average		6.156	3.637	4.226	
10/90	28a 6.35	4.608	2.322	7.828	+3.3
	9.525	4.567	2.334		
	12.7	4.517	2.324		
	28b 12.7	4.546	2.305	7.687	
	28c 12.7	4.561	2.312	7.846	
Average		4.570	2.319	7.787	
5/95	27a 6.35	4.379	2.230	8.067	+2.8
	9.525	4.365	2.218		
	12.7	4.350	2.227		
	27b 12.7	4.389	2.221	8.316	
	27c 12.7	4.386	2.212	7.897	
Average		4.373	2.222	8.093	
0/100	29a 6.35	4.613	2.143	8.361	+4.4
	9.525	4.622	2.148		
	12.7	4.605	2.147		
	29b 12.7	-----	-----	-----	
	29c 12.7	4.632	2.127	7.867	
Average		4.617	2.141	7.867	

Appendix

Complete data set for the B_4C/Cu compositions.

1. Longitudinal and shear velocity, Young's modulus, shear modulus, and Poisson's ratio for each temperature determination in the order the data was taken.
2. Plots of longitudinal and shear velocity versus temperature.
3. Plots of normalized moduli versus temperature.

SAMPLE #11 BC 80% CU 20 INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
20	3.735	6.78	24	6.282	16.58	6.75	.228
91	3.69	6.61	188	6.021	15.72	6.52	.206
161	3.593	6.26	178	5.804	14.35	6.2	.157
228	3.519	6	248	5.581	14	6.01	.165
299	3.558	6.13	312	5.431	13.81	6.17	.12
367	3.613	6.3	377	5.341	13.58	6.3	.078
434	3.595	6.22	444	5.215	13	6.16	.055
505	3.515	5.92	510	5.191	12.75	5.91	.079
569	3.527	5.94	588	5.288	12.78	5.83	.078
572	3.728	6.84	638	5.314	13.42	6.52	.029
643	3.686	6.5	726	4.801	10.72	4.8	.085
710	3.931	5.27	876	5.844	11.91	5.5	.083
764	2.96	4.15	719	4.776	10.73	5.05	.083
811	2.75	3.58	737	4.848	10.12	4.7	.077
-43	3.86	7.24	757	4.585	9.54	4.25	.123
25	3.726	6.75	782	4.989	8.79	3.88	.133
			888	4.91	8.35	3.64	.147
			-39	6.419	17.81	7.23	.218
			25	6.253	16.53	6.75	.225

SAMPLE #11 BC 80% CU 20% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
684	3.39	5.46	739	4.882	10.6	4.75	.116
587	3.639	6.32	701	4.982	11.49	5.2	.108
446	3.925	7.41	649	5.185	12.59	5.8	.088
386	4.009	7.76	619	5.312	13.24	6.11	.084
288	4.121	8.22	588	5.331	13.4	6.25	.073
174	4.886	8.14	543	5.452	14.13	6.7	.055
114	4.061	8.01	483	5.512	14.58	7.18	.015
87	4.028	7.88	493	5.654	15.38	7.48	.027
21	3.995	7.76	355	5.852	16.45	7.82	.052
25	3.726	6.75	381	6.082	17.26	8.08	.068
			247	6	17.33	8.21	.058
			23	5.742	15.89	7.78	.031
			79	5.719	15.89	7.87	.01
			155	5.582	16.17	8.08	0
			210	5.537	16.4	8.2	0
			281	5.587	16.29	8.15	0
			342	5.51	15.79	7.9	0
			413	5.44	15.18	7.58	0
			488	5.33	14.24	7.12	0
			530	5.303	13.58	6.79	0
			257	5.871	16.89	8.22	.016
			289	5.795	16.97	8.19	0

SAMPLE #11 B₄C 80% Cu 20%

SAMPLE #11 B₄C 80% Cu 20%

SAMPLE #12 BC 70% CU 30% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
18	3.631	8.07	24	6.1	19.74	8.84	.228
59	3.611	7.97	103	6.088	19.2	7.74	.241
101	3.56	7.73	163	5.884	18.27	7.57	.287
143	3.541	7.63	237	5.583	17.19	7.2	.184
187	3.518	7.52	296	5.443	16.45	6.85	.184
240	3.438	7.16	357	5.477	15.86	6.5	.22
283	3.411	7.84	424	5.584	15.58	6.21	.253
327	3.336	6.72	488	5.798	15.81	6.18	.279
372	3.245	6.35	568	5.681	15.44	6.88	.27
417	3.214	6.23	648	5.45	14.28	5.84	.287
463	3.178	6.07	703	5.289	12.9	5.88	.27
535	3.227	6.24	775	4.837	10.85	4.24	.28
602	3.145	5.91	884	4.772	9.9	3.8	.383
673	3.001	5.38	-45	6.274	20.6	8.33	.237
720	2.923	5.07	25	6.088	19.71	8.84	.228
764	2.71	4.35					
-41	3.682	8.91					
25	3.622	8.03					

SAMPLE #12 BC 70% CU 30% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
716	2.991	5.31	683	5.515	14.47	5.7	.27
698	3.002	5.36	677	5.474	14.85	5.83	.257
657	3.206	6.12	578	5.781	16.63	6.65	.251
622	3.261	6.34	493	5.957	17.78	7.12	.249
600	3.231	6.23	432	6.097	18.86	7.58	.244
563	3.373	6.81	388	6.157	19.24	7.73	.245
482	3.452	7.16	351	6.258	19.75	7.91	.249
439	3.541	7.55	326	6.283	19.98	8	.248
381	3.582	7.74	26	6.228	20.01	8.84	.244
344	3.62	7.92	71	6.195	19.88	7.9	.246
251	3.68	8.21	142	6.176	19.59	7.88	.243
168	3.876	8.22	201	6.13	19.35	7.8	.241
82	3.594	7.89	275	6.111	18.98	7.62	.246
25	3.622	8.03	340	5.983	18.45	7.45	.239
			408	5.868	17.85	7.25	.232
			432	5.824	17.68	7.2	.228
			488	5.95	18.02	7.25	.243
			353	6.03	18.44	7.4	.246
			21	6.228	20.02	8.05	.244
			25	6.088	19.71	8.84	.228

SAMPLE #12 B₄C 70% Cu 30%

SAMPLE #12 B₄C 70% Cu 30%

SAMPLE #13 BC 80% CU 40% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
18	3.615	8.37	22	6.22	23.26	8.93	.247
121	3.557	8.04	98	6.023	22.38	8.1	.23
200	3.512	8.79	184	5.873	21.58	8.84	.22
289	3.46	8.48	257	5.833	21.82	8.58	.225
368	3.435	8.32	328	5.817	20.88	8.41	.23
425	3.431	8.22	388	6.822	20.8	8.25	.261
498	3.458	8.27	458	6.131	20.94	8.25	.268
563	3.435	8.13	517	5.921	20.44	8.22	.244
635	3.228	7.15	584	5.781	19.53	7.88	.24
709	2.922	5.84	657	5.835	18.93	6.6	.283
759	2.745	5.15	742	5.525	14.14	5.32	.329
780	2.685	4.82	814	5.519	12.25	4.5	.382
790	2.674	4.88	-41	6.381	24.45	8.8	.248
-42	3.685	8.8	25	6.287	23.23	8.93	.245
25	3.688	8.33					

SAMPLE #13 BC 80% CU 40% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
647	3.164	6.88	741	5.987	15.83	5.58	.348
681	3.287	7.47	889	6.171	17.45	6.55	.333
548	3.387	7.82	854	6.235	17.89	6.72	.332
484	3.439	8.2	581	6.481	19.99	7.6	.316
447	3.481	8.43	543	6.588	20.58	7.81	.318
389	3.587	8.92	487	6.571	21.33	8.12	.314
368	3.618	9.23	458	6.593	21.9	8.37	.308
324	3.648	9.42	487	6.678	22.84	8.65	.309
285	3.658	9.49	381	6.756	23.88	8.22	.289
241	3.685	9.66	348	6.721	24.15	8.34	.293
184	3.789	9.8	29	6.733	24.23	8.93	.289
185	3.678	9.68	25	6.287	23.23	8.93	.245
16	3.781	9.83					
112	3.652	9.54					
185	3.686	9.28	21	6.764	25.22	9.8	.287
284	3.683	9.21	187	6.789	24.82	8.55	.289
237	3.638	8.41	182	6.782	23.89	9.25	.297
188	3.647	8.49	284	6.712	23.9	9.21	.298
25	3.688	8.33	388	6.682	23.29	8.95	.301
			482	6.482	21.72	8.35	.301
			547	6.315	20.31	7.8	.302
			644	6.895	18.83	6.85	.318
			712	5.838	15.85	5.97	.328
			752	5.749	14.5	5.4	.343
			815	5.458	12.22	4.5	.358
			584	6.255	19.6	7.5	.307
			553	6.358	20.24	7.74	.308
			488	6.589	22.92	8.85	.285
			319	6.762	24.35	9.4	.288
			25	6.287	23.23	8.93	.245

SAMPLE #13 B₄C 60% Cu 40%

SAMPLE #13 B₄C 60% Cu 40%

SAMPLE #13 B_4C 60% Cu 40%

SAMPLE #14 BQ 50% CU 50% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
21	3.439	8.93	25	5.861	22.83	8.89	.239
111	3.374	8.57	88	5.712	21.24	8.64	.228
168	3.357	8.46	188	5.743	20.95	8.44	.241
233	3.345	8.38	271	5.729	20.6	8.27	.246
326	3.295	8.88	383	5.787	19.98	7.97	.254
418	3.253	7.78	449	5.377	18.75	7.73	.213
515	3.239	7.58	512	5.834	17.39	7.58	.147
604	3.86	6.72	613	4.771	15.32	6.6	.161
701	2.888	5.63	689	4.685	13.72	5.62	.221
724	2.688	5.15	771	4.486	11.66	4.82	.262
807	2.472	4.35	797	4.588	11.25	4.39	.282
-41	3.584	9.28	885	4.523	11.19	4.35	.287
25	3.431	8.89	-41	6.184	23.35	9.32	.253
			25	5.849	22	8.89	.238

SAMPLE #14 BQ 50% CU 50% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
711	2.782	5.57	725	4.78	13.49	5.38	.254
668	2.915	6.88	639	5.278	16.27	6.45	.262
591	3.882	6.87	572	5.441	17.55	6.99	.256
548	3.161	7.2	447	5.631	19.31	7.74	.248
482	3.217	7.51	383	5.718	20.43	8.23	.241
424	3.328	8.14	353	5.763	20.84	8.39	.242
366	3.356	8.35	312	5.815	21.22	8.53	.244
335	3.376	8.48	287	5.87	21.55	8.84	.248
279	3.391	8.58	24	5.825	21.98	8.9	.234
288	3.46	8.97	70	5.852	22.12	8.96	.234
114	3.451	8.96	171	5.765	21.89	8.98	.219
116	3.451	8.96	233	5.794	21.74	8.85	.228
75	3.449	8.97	325	5.758	21.83	8.5	.238
19	3.439	8.93	25	5.849	22	8.89	.238
25	3.431	8.89					

SAMPLE #14 B_4C 50% Cu 50%

SAMPLE #14 B₄C 50% Cu 50%

SAMPLE #15 BC 40% CU 60% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
19	3.207	9.23	25	5.885	23.7	9.19	.29
102	3.167	8.96	104	5.818	23.13	8.97	.29
178	3.133	8.76	194	5.777	22.54	8.72	.293
268	3.102	8.55	283	5.795	22.17	8.53	.3
353	3.098	8.45	370	5.707	21.62	8.35	.295
452	2.992	7.76	460	5.555	19.87	7.65	.289
544	2.85	5.98	613	4.425	13.43	5.31	.265
633	2.462	5.13	609	4.405	13.43	5.33	.261
704	2.288	4.43	694	4.096	11.54	4.57	.263
712	2.29	4.43	772	3.842	10.25	4.08	.257
811	2.149	3.9	812	3.797	9.82	3.88	.266
816	2.161	3.94	-41	6.035	24.25	9.32	.301
-40	3.218	9.31	25	5.885	23.7	9.19	.29
25	3.2	9.18					

SAMPLE #15 BC 40% CU 60% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
784	2.261	4.32	723	4.254	12.48	4.95	.261
602	2.643	5.92	691	4.349	13.15	5.23	.257
501	2.700	6.55	619	4.523	14.5	5.81	.248
415	2.885	7.27	591	4.63	15.01	5.98	.255
335	2.907	7.47	523	4.752	16.03	6.41	.251
261	2.937	7.67	486	4.857	16.77	6.7	.252
125	2.945	7.75	450	4.862	17.37	7	.241
129	2.945	7.75	403	4.928	18.1	7.31	.239
132	2.958	7.82	312	5.085	18.94	7.55	.254
19	2.983	8.03	278	5.126	19.18	7.63	.257
25	3.2	9.18	235	5.122	19.31	7.7	.254
			203	5.13	19.39	7.73	.254
			20	5.157	19.99	8.02	.247
			78	5.069	19.6	7.92	.237
			81	5.105	19.68	7.92	.243
			142	5.081	19.41	7.8	.245
			204	5.075	19.28	7.74	.246
			277	5.063	19.04	7.63	.248
			25	5.885	23.7	9.19	.29

SAMPLE #15 B_4C 40% Cu 60%

SAMPLE #15 B_4C 40% Cu 60%

SAMPLE #16 BQ 30% CU 70% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
20	2.893	8.07	24	5.445	20.99	8.05	.304
106	2.873	7.94	105	5.366	20.65	7.95	.299
199	2.833	7.69	186	5.272	20.83	7.73	.296
286	2.822	7.58	274	5.323	19.82	7.6	.304
372	2.746	7.12	363	5.269	18.87	7.2	.311
460	2.685	6.63	456	4.9	17.11	6.66	.285
555	2.573	6	526	4.371	15.19	6.21	.223
620	2.43	5.33	585	4.192	13.79	5.63	.226
628	2.434	5.35	671	3.948	12.2	4.98	.226
718	2.27	4.64	740	3.786	10.84	4.45	.219
813	2.077	3.87	749	3.834	10.99	4.39	.252
-40	2.908	8.17	815	3.67	9.75	3.85	.267
25	2.887	8.04	-43	5.592	21.5	8.18	.314
			25	5.445	20.99	8.05	.304

SAMPLE #16 BQ 30% CU 70% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
749	2.247	4.54	799	3.781	10.21	4.01	.273
668	2.472	5.5	713	4.148	12.65	5.02	.261
612	2.558	5.91	658	4.335	13.98	5.57	.255
564	2.632	6.28	646	4.292	14.06	5.66	.243
503	2.7	6.65	569	4.482	15.41	6.21	.241
441	2.752	6.99	488	4.621	16.46	6.62	.244
335	2.784	7.34	445	4.663	17.23	6.98	.235
257	2.81	7.53	351	4.767	18.12	7.28	.245
197	2.836	7.7	310	4.819	18.48	7.41	.247
118	2.835	7.73	282	4.822	18.63	7.48	.245
134	2.835	7.73	24	4.904	19.67	7.93	.24
21	2.868	7.93	77	4.914	19.46	7.8	.248
25	2.887	8.04	160	4.835	19.11	7.72	.238
			227	4.834	18.93	7.63	.241
			293	4.785	18.47	7.45	.24
			111	4.866	19.25	7.75	.242
			25	5.445	20.99	8.05	.304

SAMPLE #16 B₄C 30% Cu 70%

SAMPLE #16 B₄C 30% Cu 70%

SAMPLE #17 BC 80X CU 20X INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
21	3.588	8.15	24	8.08	15.18	8.18	.233
79	3.454	5.7	78	5.98	14.25	5.72	.248
166	3.254	5.85	165	5.7	12.73	5.88	.258
231	3.232	4.98	231	5.757	12.87	4.98	.27
301	3.241	5	294	5.84	12.54	5	.254
367	3.154	4.73	368	5.579	11.91	4.7	.288
437	3.128	4.85	481	5.421	11.55	4.81	.253
498	3.089	4.55	521	5.272	11.23	4.54	.237
565	3.088	4.54	598	5.481	11.38	4.48	.288
631	3.088	4.43	674	5.158	9.78	3.82	.28
641	2.952	4.1	744	4.781	8.24	3.2	.288
686	2.822	3.75	781	4.485	7.32	2.85	.285
767	2.534	3.81	888	4.482	7.28	2.84	.282
788	2.483	2.84	-41	8.383	18.88	8.84	.219
881	2.481	2.84	25	8.08	15.18	8.18	.233
-48	3.778	8.84					
25	3.588	8.15					

SAMPLE #17 BC 80X CU 20X DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
885	2.941	4.87	758	4.851	8.55	3.33	.285
574	3.227	4.92	678	5.258	10.58	4.18	.283
515	3.3	5.18	598	5.581	11.83	4.78	.248
444	3.384	5.45	558	5.843	12.48	4.88	.252
388	3.418	5.55	481	5.824	13.84	5.18	.284
385	3.518	5.8	422	5.872	13.88	5.5	.28
218	3.517	5.8	351	6.141	14.54	5.75	.285
126	3.471	5.78	284	6.254	14.97	5.8	.288
129	3.463	5.73	282	6.225	14.82	5.88	.287
88	3.394	5.51	181	6.18	14.78	5.87	.281
82	3.418	5.58	25	5.923	13.71	5.44	.28
21	3.388	5.43	77	5.878	13.73	5.48	.251
25	3.588	8.15	131	5.878	14.18	5.75	.233
			282	5.858	14.38	5.88	.219
			123	5.88	14.18	5.73	.236
			84	5.888	13.78	5.51	.251
			25	8.08	15.18	8.18	.233

SAMPLE #17 B₄C 80% Cu 20%

SAMPLE #17 B₄C 80% Cu 20%

SAMPLE #18 BC 70X CU 30X INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
18	3.641	8.12	22	6.156	19.86	8.1	.232
99	3.559	7.73	104	5.851	18.63	7.72	.207
102	3.632	8.05	182	5.327	15.84	6.55	.194
180	3.3	6.62	250	5.025	13.40	5.55	.216
275	2.992	5.42	339	5.438	15.42	6.27	.23
344	3.224	6.28	343	5.652	15.70	6.27	.258
405	3.23	6.29	408	5.59	15.7	6.28	.25
481	3.244	6.32	476	5.583	15.67	6.3	.244
553	3.233	6.26	575	5.438	14.74	5.9	.25
624	2.997	5.36	675	5.276	12.54	4.85	.293
673	2.871	4.91	773	4.845	10.29	3.95	.303
-41	3.709	8.43	813	4.735	9.46	3.6	.315
25	3.637	8.1	-42	6.3	20.83	8.43	.238
			25	6.156	19.86	8.1	.232

SAMPLE #18 BC 70X CU 30X DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
621	3.185	5.75	772	5.057	11.32	4.38	.288
576	3.173	6.02	782	5.485	12.98	5	.298
541	3.24	6.29	853	5.588	14.01	5.42	.293
485	3.306	6.56	575	5.738	15.41	6.82	.28
436	3.378	6.87	538	5.85	16.14	6.32	.277
401	3.385	6.9	476	5.882	16.85	6.68	.266
361	3.479	7.3	431	6.012	17.40	6.88	.269
334	3.504	7.42	375	6.149	18.28	7.2	.268
283	3.541	7.59	341	6.211	18.72	7.38	.269
269	3.563	7.69	28	6.143	19.83	8.1	.231
234	3.539	7.59	84	6.15	19.59	7.9	.24
223	3.525	7.54	138	6.09	19.12	7.7	.242
25	3.637	8.1	238	6.098	18.85	7.55	.249
			298	6.001	18.08	7.58	.235
			366	5.969	18.11	7.28	.244
			433	5.889	17.28	6.88	.254
			185	6.285	19.18	7.54	.272
			79	6.257	19.8	7.9	.253
			25	6.156	19.86	8.1	.232

SAMPLE #18 B₄C 70% Cu 30%

SAMPLE #18 B₄C 70% Cu 30%

SAMPLE #27 BC 5X CU 95X INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
19	2.228	5.82	23	4.388	15.39	5.8	.327
99	2.188	5.8	71	4.348	15.88	5.88	.328
159	2.168	5.47	131	4.259	14.85	5.54	.329
229	2.152	5.91	223	4.228	14.1	5.32	.325
298	2.135	5.15	284	4.227	13.78	5.19	.328
363	2.184	4.85	358	4.179	13.24	4.98	.328
438	2.886	4.73	422	4.823	12.51	4.74	.321
508	1.978	4.29	485	3.858	11.98	4.31	.321
568	1.882	3.88	588	3.888	10.13	3.88	.313
635	1.728	3.23	649	3.321	8.47	3.22	.316
707	1.622	2.84	718	3.127	7.3	2.78	.323
777	1.483	2.4	813	3.187	5.88	2.15	.360
-48	2.289	8.88	-45	4.473	18.1	8.87	.328
25	2.222	5.79	25	4.373	15.37	5.8	.328

SAMPLE #27 BC 5X CU 95X DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
689	1.849	2.84	727	3.314	7.44	2.76	.348
592	1.786	3.39	728	3.298	7.52	2.8	.343
539	1.817	3.8	649	3.428	8.27	3.88	.34
484	1.844	3.73	588	3.588	8.15	3.45	.327
508	1.752	3.33	515	3.549	9.88	3.88	.32
533	1.824	3.83	475	3.597	10.82	3.8	.319
414	1.885	3.89	473	3.589	10.81	3.81	.314
368	1.911	4.88	417	3.831	10.45	3.88	.313
328	1.817	4.14	383	3.849	10.59	4.83	.314
268	1.825	4.22	358	3.888	10.77	4.1	.313
194	1.833	4.34	278	3.889	11.86	4.21	.315
134	1.837	4.37	241	3.727	11.17	4.24	.318
28	1.97	4.55	228	3.723	11.22	4.26	.317
85	1.848	4.44	175	3.73	11.41	4.33	.318
148	1.825	4.32	125	3.754	11.54	4.38	.318
215	1.824	4.27	81	3.755	11.72	4.48	.315
174	1.834	4.35	27	3.788	11.92	4.53	.316
138	1.945	4.41	25	4.373	15.37	5.8	.326
25	2.222	5.79					

SAMPLE #27 B₄C 5% Cu 95%

SAMPLE #27 B₄C 5% Cu 95%

SAMPLE #28 BQ 10X CU 90X INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
19	2.315	6.85	16	4.559	16.17	6.11	.324
105	2.266	5.8	99	4.514	15.62	5.88	.328
163	2.273	5.8	188	4.438	15.21	5.75	.323
230	2.238	5.58	268	4.372	14.67	5.55	.322
321	2.215	5.37	358	4.359	13.89	5.22	.331
386	2.159	5.02	452	3.971	11.28	4.25	.327
459	1.985	4.12	528	3.585	9.58	3.85	.311
538	1.878	3.62	585	3.341	8.51	3.28	.288
600	1.781	3.24	668	3.189	7.37	2.81	.313
676	1.649	2.75	747	3.884	6.43	2.42	.329
690	1.625	2.67	824	3.235	5.53	2	.382
747	1.552	2.43	-43	4.856	16.89	6.38	.324
777	1.585	2.28	25	4.559	16.89	6.07	.326
-41	2.362	6.31					
25	2.311	6.83					

SAMPLE #28 BQ 10X CU 90X DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
758	1.611	2.62	722	3.584	7.49	2.76	.357
728	1.645	2.74	645	3.623	8.47	3.15	.345
676	1.715	2.98	585	3.724	9.17	3.42	.341
601	1.816	3.36	489	3.814	10.89	3.79	.332
504	1.982	3.73	432	3.857	10.63	4	.33
452	1.936	3.93	348	3.883	11.24	4.24	.328
406	1.95	4.07	218	3.929	11.79	4.45	.328
358	1.973	4.23	166	3.932	11.92	4.5	.325
303	1.989	4.35	167	3.91	11.9	4.5	.322
19	2.039	4.69	113	3.935	12.11	4.58	.323
83	2.028	4.64	88	3.952	12.17	4.6	.324
142	1.996	4.48	21	3.981	12.42	4.7	.322
208	1.994	4.45	25	4.559	16.89	6.07	.326
258	1.985	4.37					
327	1.971	4.26					
25	2.319	6.87					

SAMPLE #28 B_4C 10% Cu 90%

SAMPLE #28 B₄C 10% Cu 90%

SAMPLE #29 BC 8% CU 100% INCREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
24	2.148	5.25	23	4.839	14.27	5.23	.385
138	2.112	5.07	183	4.588	13.82	5.1	.388
200	2.076	4.87	185	4.583	13.82	5.1	.385
260	2.063	4.79	188	4.588	13.81	5	.382
342	2.084	4.77	227	4.48	13.24	4.88	.382
343	2.081	4.85	294	4.517	13.1	4.79	.388
408	2.08	4.58	295	4.522	13.1	4.79	.388
489	2.059	4.55	360	4.527	12.84	4.73	.389
473	2.013	4.21	428	4.546	12.37	4.51	.372
477	2.011	4.21	422	4.537	12.34	4.5	.371
546	1.924	3.78	497	4.499	11.19	4.87	.375
610	1.775	3.19	498	4.483	11.17	4.87	.372
693	1.643	2.73	559	4.259	9.97	3.62	.378
768	1.576	2.48	584	4.187	9.81	3.57	.375
811	1.528	2.34	635	3.583	8.17	3.83	.349
-40	2.182	5.40	638	3.522	8.1	3.82	.341
25	2.141	5.23	718	3.438	7.21	2.88	.358
			798	3.382	6.48	2.37	.368
			822	3.383	6.31	2.3	.373
			-42	4.711	14.85	5.49	.382
			25	4.617	14.25	5.23	.383

SAMPLE #29 BC 8% CU 100% DECREASING TEMPERATURE DATA

DEGREE C	SHEAR VELOCITY MM/MSEC	SHEAR MODULUS MPSI	DEGREE C	LONG. VELOCITY MM/MSEC	YOUNG'S MODULUS MPSI	SHEAR MODULUS MPSI	POISSON'S RATIO
811	1.528	2.34	822	3.383	6.31	2.3	.373
775	1.591	2.54	733	3.472	7.89	2.6	.384
774	1.58	2.51	733	3.489	7.88	2.59	.384
694	1.657	2.76	682	3.523	7.84	2.82	.355
644	1.7	2.92	688	3.588	8.1	3	.35
583	1.723	3.01	528	3.651	8.78	3.27	.343
544	1.753	3.14	447	3.679	9.33	3.49	.337
507	1.888	3.38	481	3.685	9.68	3.62	.335
483	1.789	3.35	385	3.685	9.85	3.89	.335
475	1.812	3.41	334	3.688	10.13	3.8	.334
423	1.845	3.61	24	3.765	10.88	4.89	.331
398	1.847	3.68	82	3.728	10.71	4.83	.329
359	1.85	3.78	87	3.734	10.72	4.83	.33
343	1.844	3.8	155	3.725	10.57	3.97	.331
321	1.849	3.83	225	3.784	10.41	3.91	.332
26	1.896	4.1	25	4.617	14.25	5.23	.383
77	1.887	4.85					
98	1.885	4.84					
171	1.888	3.95					
210	1.885	3.94					
261	1.848	3.85					
284	1.851	3.85					
25	2.141	5.23					

SAMPLE #29 B₄C 0% Cu 100%

SAMPLE #29 B₄C 0% Cu 100%

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