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COMMENTS ON THE COMPARISON OF DYNAMIC AND STATIC COMPRESSION DATA*

R. GROVER
Lawrence Radiation Laboratory, University of California, Livermore, Calif. 94550, U.S.A.

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Abstract—A detailed discussion is presented of the relationship between dynamic shock wave data at high pressures, acoustic velocity data at low pressures and the static compression data at intermediate pressures reported by Vaidya and Kennedy in the previous paper.

1. INTRODUCTION

In the previous paper[1] by Vaidya and Kennedy (VK) it was possible for the first time to make an extensive comparison of the compressions of a number of metals determined by three completely independent experimental methods. The compression data for 16 metals obtained by VK in a static, high-pressure, piston-cylinder apparatus were found to be in agreement with the isothermal compressions calculated from shock wave data up to 45 kbar. Such a comparison is of great importance, for instance, in detecting systematic errors in pressure scales developed in static and dynamic high pressure experiments[2].

The purpose of this note is to identify the shock data used in the comparison by VK and to discuss the validity of extrapolating shock data to low pressures for such a comparison. In connection with this discussion the relationship between measurements of sound velocity at very low pressure and shock velocity data at high pressures is reviewed and a comparison of both kinds of velocity data is made for the metals studied by VK. On the basis of this comparison the consistency between static and dynamic compression data is strengthened.

The reduction of shock compression data on metals to isothermal compression was extensively reviewed in the original survey article by Rice, McQueen, and Walsh[3]. In this and much of the subsequent work most attention has been given to the reduction of shock data at high pressures and the extrapolation to low pressures was limited to a comparison with the older compressibility data on metals by Bridgman. In a number of these metals low pressure phase transitions are now known and have been detected in shock wave experiments. When no transition is present newer ultrasonic velocity data can now be used in conjunction with high pressure shock data to obtain more accurate compression curves at low pressure. Little thermodynamic equation-of-state information has been extracted directly from shock wave experiments at low pressures in the vicinity of the elastic yield strength because of the more complicated nature of shock wave propagation at low pressures.

2. SHOCK WAVE DATA

Most of the shock compression values quoted by VK are taken from an extensive AIP Handbook tabulation of isothermal compression P–V curves derived from shock data as reported by Keeler[4]. The isotherms were calculated from shock data as fitted in the usual way by a polynomial expansion of the shock velocity U_s in powers of the material or particle velocity U_p,

$$U_s = C + SU_p + S_2 U_p^2 + \cdots$$

The fits used in the handbook tabulation are identified by an asterisk in Table 1 and were

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Table 1. Comparison of shock wave and sonic velocity data

	Shock							Sonic		
Mat.	ρ_x† (g/cc)	ρ_0 (g/cc)	C (cm/μsec)	S	S_2 (μsec/cm)	S_3 (μsec/cm)^2	Ref.	C (cm/μsec)	S	Ref.
Ag	10·494	10·49	0·322*	1·52			[a]	0·314	1·75	[S1, S2]
Al	2·698	2·78	0·528*	1·50	−0·67	0·41	[b]	0·532	1·48	[S3, S4]
Au	19·302	19·24	0·312*	1·52			[a]	0·300	1·82	[S1, S2]
			0·294	1·87	−1·38		[c]			
Ba	3·65	3·75	0·159	0·88			[d]	0·159		[d]
Ca	1·53	1·56	0·346	0·99			[d]	0·331		[d]
Cd	8·642	8·64	0·238	1·75			[e]	0·237	1·89	[S5, S6]
			0·247*	1·66			[a]			
Cu	8·932	8·90	0·401*	1·47			[a]	0·392	1·62	[S1, S2]
Fe	7·873	7·85	0·460	1·43			[a]	0·460	1·56	[S7, S8]
In	7·286	7·28	0·239*	1·55			[f]	0·239		[S9]
La	6·174	6·135	0·208	1·12			[g]	0·213		[g]
Mo	10·220	10·17	0·514*	1·26			[a]	0·513		[S10, S15]
Ni	8·907	8·86	0·465*	1·45			[h]	0·454		[S11]
Pb	11·341	11·34	0·201*	1·54			[a]	0·199	1·58	[S12, S13]
Sn	7·285	7·29	0·275	1·37			[i]	0·275		[S14]
Ta	16·626	16·67	0·345*	1·20			[a]	0·340		[S15]
Zn	7·134	7·13	0·298*	1·65	−0·26		[a]	0·294		[S16]

[a] VAN THIEL M. and KUSUBOV A. S., *Compendium of Shock Wave Data*, Vol. 1 and 2, UCRL-50108 1966 plus 1967 supplement). Available from Clearinghouse for Federal Scientific and Technical Information, NBS, U.S. Dept. of Commerce, Springfield, Va 22151.

[b] From unpublished fit to LRL shock data on Al 2024 and sonic data. The data of G. D. Anderson, D. G. Doran, and A. L. Fahrenbruch on a purer alloy Al 1060 is fit by 0·539 + 1·34 U_p. Below 50 kbar there is a negligible difference in V/V_0.

[c] PASTINE D. J. and PIACESI D., *J. Phys. Chem. Solids* **27**, 1783 (1966).

[d] LARSON D. B., *Lawrence Radiation Lab., Livermore*, (private communication). With the use of standard flash gap techniques transition pressures of ~180 and 70 kbar were established in Ca and Ba respectively. The reason for the high sample densities relative to X-ray values is not known.

[e] WALSH J. M., RICE M. H., McQUEEN R. G. and YARGER F. L., *Phys. Rev.* **108**, 196 (1957).

[f] McQUEEN R. G. and MARSH S. P., *Los Alamos Scientific Lab. Rep.* No. GMX-6-566 (unpublished)—see also [a].

[g] GUST W. H., *Lawrence Radiation Lab., Livermore*, (private communication), AL'TSCHULER L. V., BAKANOVA A. A. and DUDOLADOV I. P., *Zh. ETF Pis'ma* **3**, 483 (1966); *Soviet Phys. JETP Lett.* **3**, 315 (1966).

[h] McQUEEN R. G. and MARSH S. P., *J. appl. Phys.* **31**, 1253 (1960).

[i] KARTH J., *Lawrence Radiation Lab., Livermore*, (private communication), a transition was located by a method utilizing an inclined, internally reflecting prism at $U_s = 0·33$, $U_p = 0·038$, or a shock pressure ~94 kbars.

[S1] DANIELS W. B. and SMITH C. S., *Phys. Rev.* **111**, 713 (1958).
[S2] CHANG Y. A. and HIMMEL L., *J. appl. Phys.* **37**, 3567 (1966).
[S3] SCHMUNK R. E. and SMITH C. S., *J. Phys. Chem. Solids* **9**, 100 (1959).
[S4] VALLIN J., MONGY M., SALAMA K. and BECKMAN O., *J. appl. Phys.* **35**, 1825 (1964).
[S5] CORLL J. A., (unpublished ONR Report #6, June 1962, Case Inst. of Tech.).
[S6] GARLAND C. W. and SILVERMAN J., *Phys. Rev.* **119**, 1218 (1960).
[S7] GUINAN M. W. and BESHER D. N., *J. Phys. Chem. Solids* **29**, 541 (1968).
[S8] LORD A. E. and BESHER D. N., *J. appl. Phys.* **36**, 1620 (1965).
[S9] CHANDRASEKHAR B. S. and RAYNE J. A., *Phys. Rev.* **124**, 1011 (1961).
[S10] BOLEF D. I. and DE KLERK J., *J. appl. Phys.* **33**, 2311 (1962).
[S11] ALERS G. A., NEIGHBOURS J. R. and SATO H., *J. Phys. Chem. Solids* **13**, 40 (1960).
[S12] MILLER R. A. and SCHUELE D. E., *J. Phys. Chem. Solids* **30**, 589 (1969).
[S13] WALDORF D. L., ALERS G. A., *J. appl. Phys.* **33**, 3266 (1962).
[S14] RAYNE J. A. and CHANDRASEKHAR B. S., *Phys. Rev.* **120**, 1658 (1960).
[S15] FEATHERSTONE F. H. and NEIGHBOURS J. R., *Phys. Rev.* **130**, 1324 (1963).
[S16] ALERS G. A. and NEIGHBOURS J. R., *J. Phys. Chem. Solids* **7**, 58 (1958).