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Ultrasonic studies of aluminium in the temperature range 293 K to 925 K*

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Abstract: Using ultrasonic velocity and density data available in literature, various acoustical and thermodynamical parameters of aluminium metal have been evaluated in the temperature range 293 K to 925 K. The parameters studied are Gruneisen parameters, adiabatic compressibility, isothermal compressibility, thermal conductivity coefficient, interatomic distance, thermal constant and interatomic interaction energy. Acoustical parameters such as molar sound velocity, molar adiabatic compressibility and acoustic impedance are also determined. The parameters studied have been used to explain the interatomic interactions present in the system. It is observed that present method of analysis provides quantitative knowledge about the macroscopic behaviour of aluminium metal in the temperature range under investigation.

Keywords: Ultrasonics, thermodynamical parameters, acoustical behaviour, interatomic interaction.

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1. Introduction

The study of acoustic-wave propagation constants in dielectric, metallic and other types of crystals can reveal some reliable and useful information about the structure (specifically defects), dislocations and electronic-bond nature of crystals. Various investigators (Tandon and Kor 1973, Kor and Yadav 1982, Singh 1987) have shown that the ultrasonic technique can be successfully applied for predicting several useful properties of alloys and semiconductors.

In a recent paper Singh and Kumar (1989) have shown the applicability of this technique for studying the properties of palladium metal at low temperatures. The present study has been done with the intention to understand the acoustical and thermodynamical behaviour of aluminium metal at high temperatures.

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Many of thermo-acoustic properties of the aluminium have been measured over the past several years and a number of measurements of the elastic moduli that have been reported by Gerlich and Fisher (1969), which are used to obtain the ultrasonic longitudinal and shear velocities in the temperature range 293 K to 925 K. Other thermophysical parameters like α and C_p in the above temperature-range are taken from available literature (AIPHB 1963, Tripathi and Pandey 1977). Using ultrasonic velocities (longitudinal and shear) along (100) propagation direction of aluminium crystalline structure and density data taken from literature (Gerlich and Fisher 1969, AIPHB 1963, Tripathi and Pandey 1977) several acoustical and thermodynamical parameters of aluminium at high temperature are evaluated using standard relations described below.

2. Theory

Applying the theory of lattice dynamics in solids, Gruneisen (1926) defined dimensionless parameter Γ as :

$$\Gamma = K_s \alpha V / C_p = u_m^2 \alpha M / C_p \equiv \Gamma(u) \tag{1}$$

where K_s is the adiabatic compressibility ; α is the volume expansion cofficient ; V is the specific volume and C_p is the specific heat at constant pressure ; M is atomic weight of the metal and u_m is the average sound velocity.

The information regarding K_s can be obtained from measurements of ultrasonic wave velocities (longitudinal and shear) at elevated temperatures by using the relation reported for aluminium by Tripathi and Pandey (1977).

$$K_s = 1/d\{V_1^2 - 4/3V_s^2\} \tag{2}$$

where d is the density ; V_1 is the longitudinal wave velocity and V_s is the shear wave velocity. Also,

$$u_m^2 = \{V_1^2 - 4/3V_s^2\}$$

where u_m is the average sound velocity. Knopoff and Shapiro (1970) have reported another expression for Gruneisen parameter of the form

$$\Gamma = (\gamma - 1)/\alpha T \equiv \Gamma(\gamma) \tag{3}$$

where γ is the principal specific heat ratio and T is the absolute temperature.

Ramachandra Rao and Padmini (1960) suggested that a linear relation exists between the sound velocity and the latent heat (L) of vaporization. They concluded that the constant of proportionality for associated liquids (K) and its value for unassociated liquids (K^*) should be different. The values of thermal constant K and K^* according to this theory are

$$K = (L - R^*T)/Mu^2 \text{ and } K^* = T\alpha/\gamma \tag{4}$$

where R^* is universal gas constant, γ the specific heat ratio and M the molecular weight of liquid. In the systems where the potential energy is solely or mainly due to van der Waal-type interactions K and K^* are nearly equal. Their difference thus becomes a measure of additional interactions. The interaction energy ΔE is given by

$$\Delta E = (K - K^*)/Mu^2 \tag{5}$$

For the system under study we have also evaluated the following parameters

$$\text{Thermal conductivity} = k' = 2.8k(dN/M)^{2/3}\gamma^{-1/3}u_m \tag{6}$$

$$\text{Atomic radius} = r_m = (3B/4\pi N)^{1/3} \tag{7}$$

$$\text{Interatomic distance} = d_0 = 2(3B/4\pi N)^{1/3} \tag{8}$$

$$\text{Geometrical volume} = B = r_f V \tag{9}$$

where r_f is space filling factor. The expression given above have been taken from literature (Singh 1987).

Various acoustical parameters such as molar sound velocity (R), molar adiabatic compressibility (W), acoustic impedance (Z) and isothermal compressibility (K_T) are determined using the standard relations given elsewhere (Singh 1985, Pandey and Chaturvedi 1981, Kor and Pandey 1973). Some of the representative results are reported in Tables 1 and 2. All the parameters listed in these tables are in SI units except reported otherwise.

3. Results and discussions

From the knowledge of ultrasonic wave velocities V_l and V_s, average sound velocity (u_m) is evaluated. Using calculated u_m values and densities of aluminium Gruneisen parameters $\Gamma(u)$ and $\Gamma(\gamma)$ are estimated using the formulae (1) and (3). These results are reported in Table 1. As is apparent $\Gamma(u)$ and $\Gamma(\gamma)$ have same order of magnitude. These values show a regular increase with rise in temperature. This is expected since Γ represents the change in entropy with volume or the thermal pressure which increases with rise in temperature.

To understand the internal structure, clusering phenomenon and crystaline lattice structure in a metal Γ is the most powerful tool (Singh 1985). The increasing trend of Γ with rise in temperature points to weakening of crystalline lattice structure of aluminium metal with temperature increase.

The above conclusion is further supported by the rising trend of K^*/K and the decreasing order of interaction energy (ΔE) (Table 1) with increase in temperature of the system. The minimum value of K^*/K occurs at 293 K where the metallic bonding is strongest ($\Delta E = 64.17$ Kcal/mole). The rising temperature causes

thermal-dissociative effect and decreases the interatomic interaction by increasing interatomic distances (d_0) (Table 1). The geometrical volume (B) and atomic radii

Table 1. Some acoustical properties of Al at high temperatures.

Temp T(K)	$\Gamma(\nu)$	$\Gamma(u)$	K^*	K	K^*/K	ΔE Kcal/m	$B\times10^{n}$	r_m pm	d_0 pm
293	4.071	4.071	0.029	0.420	0.069	64.17	2.41	98.48	196.9
325	4.096	4.098	0.031	0.418	0.074	63.79	2.43	98.72	197.4
375	4.161	4.129	0.034	0.419	0.081	63.16	2.44	98.94	197.9
425	4.161	4.148	0.038	0.420	0.089	62.50	2.45	99.11	198.2
475	4.178	4.179	0.041	0.423	0.097	61.91	2.47	99.34	198.7
525	4.199	4.201	0.044	0.424	0.104	61.32	2.49	99.57	199.5
575	4.222	4.218	0.046	0.427	0.109	60.90	2.50	99.76	199.5
625	4.234	4.234	0.049	0.431	0.114	60.44	2.51	99.95	199.9
675	4.257	4.254	0.051	0.433	0.117	60.15	2.53	100.08	200.2
725	4.271	4.271	0.055	0.440	0.126	59.47	2.54	100.27	200.5
775	4.311	4.311	0.058	0.439	0.132	59.02	2.56	100.50	201.0
825	4.384	4.384	0.061	0.442	0.138	58.50	2.58	100.74	201.5
875	4.455	4.455	0.064	0.446	0.143	58.05	2.60	101.01	202.0
925	4.557	4.557	0.066	0.452	0.146	57.80	2.62	101.29	202.5

(r_m), however increase but the increase in this is small as compared to increase in interatomic distances leading to weakening of interatomic interactions or metallic

Table 2. Some acoustical and thermodynamical parameters of Al at higher temperature.

Temp T(K)	d	V_l	V_s	K_s $\times10^{11}$	R $\times10^{6}$	W $\times10^{5}$	Z $\times10^{-4}$	K_T $\times10^{11}$	k' watt/m/k
293	2702	6278	3235	1.454	171	353	1363	1.648	2.88
325	2677	6283	3331	1.462	173	356	1353	1.672	2.85
375	2648	6259	3205	1.481	175	359	1338	1.711	2.81
425	2628	6228	3175	1.501	176	361	1323	1.765	2.77
475	2601	6193	3146	1.528	177	364	1305	1.844	2.73
525	2576	6159	3111	1.543	179	367	1289	1.890	2.69
575	2554	6119	3074	1.576	180	369	1273	1.962	2.65
625	2538	6069	3031	1.603	181	370	1258	2.026	2.61
675	2513	6029	2991	1.630	182	373	1242	2.091	2.57
725	2489	5984	2947	1.672	184	375	1220	2.192	2.52
775	2467	5938	2901	1.687	186	378	1209	2.246	2.49
825	2436	5888	2855	1.723	188	382	1189	2.352	2.45
875	2410	5839	2808	1.760	190	386	1170	2.460	2.39
925	2383	5777	2756	1.805	191	388	1149	2.522	2.34

bonding which is well reflected in decreasing values of ΔE. The observed trends of K'/K and ΔE are in accordance with the results reported in literature for other metals (Jaraynski 1963).

Some acoustical and thermodynamical parameters of the system under study are reported in Table 2. The variational trends of average ultrasonic velocity (u_m) and density (d) for system report a regular decrease as the temperature is increased. The molar volume ($V=M/d$), adiabetic compressibility (K_s), molar sound velocity (R) and molar adiabetic compressibility (W) (Table 2) slowly increase with temperature rise. The temperature dependent behaviour of R and W point to the associated nature of the system under study. This is in agreement with results reported for similar systems by Bhatti *et al* (1980). The effect of temperature rise is to cause thermal expansion of the system which is well reflected in the rising trends of K_s and K_T (Table 2). The increased interatomic distance, with temperature rise effects acoustic impedance (Z) adversely which reports a decrease in its values with such a change.

Another important property of aluminium metal is thermal conductivity (k') reported in Table 2. As Al metal, when used as a coolant cool materials by absorption of the latent heat and the k' represents the ability of a material to absorb heat at one temperature and reject it at some other temperature, so higher the value of k' greater is the efficiency of a coolant.

In the present studies, k' values of aluminium decrease from 2.876 to 2.341 watt/m/k as its temperature is increased from 293 K to 925 K. It indicates greater efficiency of thermal transportation by aluminium metal at low temperatures. This trend of variation of k' with rise in temperature is similar to that reported for other metals (Singh and Kalsh 1989).

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