Measurements of Sound Speeds in Zinc and Titanium Alloys by Optical Method

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Introduction

Information on sound speed, which characterizes substance behavior under conditions of shock compression followed by release, is required to formulate the substance equations of state (EOS). The kink in the dependence of sound speed on pressure is associated with structural transitions in shock-compressed substance. Therefore, it is possible to reveal phase transitions of substance along shock adiabat, including its melting, by measuring the sound speed.

The work presents the results of experimental measurements of sound speed in two metal alloys of common application as a structural material – titanium and zinc alloys.

Experimental Setup

The rarefaction overtake method with use of indicator liquids is the most informative method for measurement of sound velocities in metals compressed up to pressures higher 30 GPa. We performed measurements of sound speeds according to the scheme described in detail in [1] with use of carbogal, tetrachlormethane, and bromoform as the indicator liquids.

In our experimental assemblies, the samples were located on base plates made of steel or aluminum. Velocity of motion of shock wave front D in the sample was recorded by electrocontact pins. The samples were loaded by impact of a liner, accelerated by HE-based generators of plane shock wave. Since materials of the base plate and the samples are different, the following formula was used to calculate sound speed: $C_{sound} = \dfrac{X_{MAX}}{s \times (t_{SW} - t_{RW} + \dfrac{X_{MAX}}{D})}$, where σ – is the compression, t_{SW} – is the time of shock wave entering the sample, t_{RW} – is the time of rarefaction wave entering the sample (the times are determined from X-t diagrams), D – is the velocity of shock wave in sample, X_{MAX} – is the thickness of step when overtaking occurs at the sample-indicator interface.

Experimental Results

Zinc. Measurements of sound velocities were performed in zinc with the initial density of 7.14 g/cm^3 in the range of 50÷180 GPa. Oscillograms of one of the tests are presented in figure 1, where t_1 – is the time of shock wave entering the indicator, t_2 – is the time when the rarefaction wave overtakes the shock wave front.

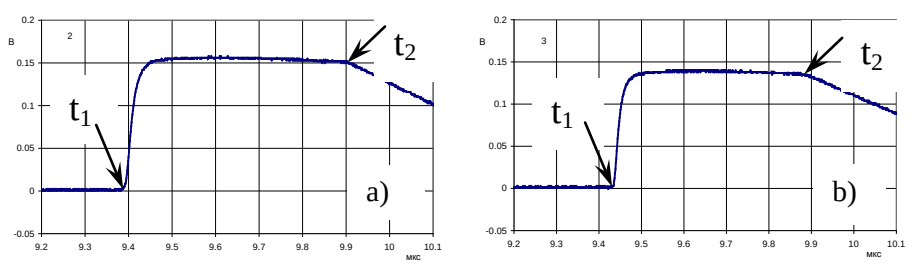

Figure 1. Irradiations of shock wave front in C_8F_{16} at P_{Zn} = 149 GPa behind zinc steps: a) 2.46 mm; b) 2.96 mm

The dependence of sound velocities in zinc on pressure of shock compression is presented in figure 2 together with calculated isentropic sound speed with use of VNIIEF EOS, as well as values of longitudinal C_L = 4.17 km/s and bulk C_B = 3.23 km/s sound velocities, which were measured by the ultrasound method in VNIIEF at the atmospheric pressure.

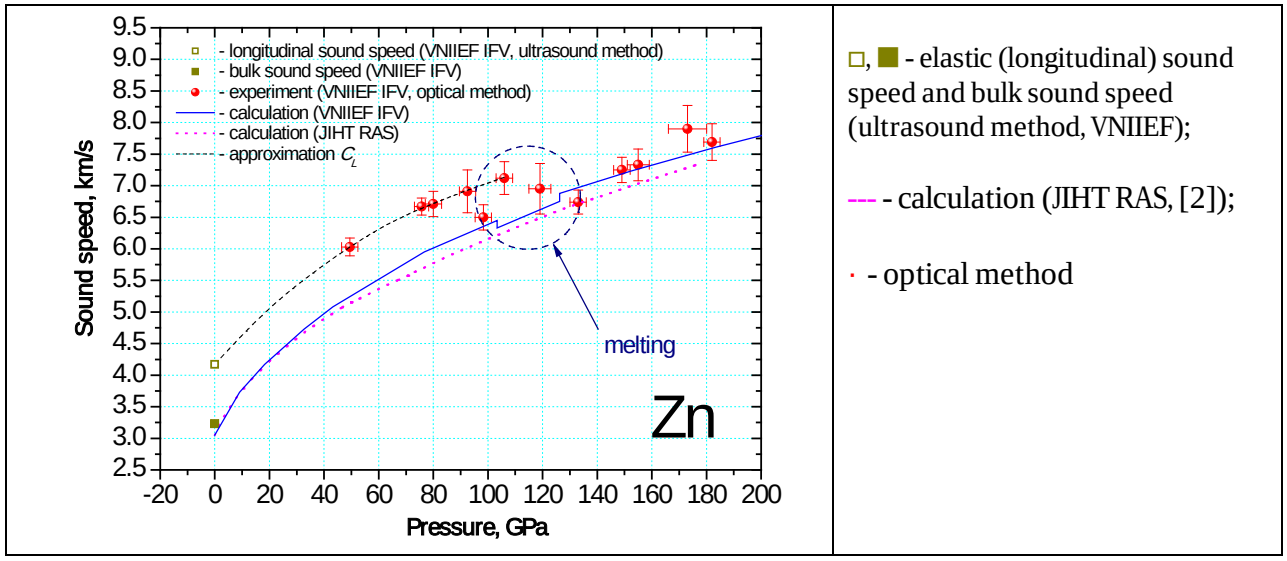

Figure 2. Dependence of sound velocities on pressure in zinc.

According to the obtained data, zinc is already in the melted state under pressures higher 105 GPa. As it is possible to see in the graph from figure 3, the data obtained under pressures higher 90 GPa (except for one point) are in the best agreement with calculation by the updated Van der Waals model within the measurement error. According to the calculation, the area of zinc melting in shock wave corresponds to the pressure range of 103-126 GPa [2]. According to the obtained experimental data, the pressure range of zinc is in the pressure range of 105÷130 GPa.

Titanium alloy VT-20. Sound speed in shock-compressed titanium alloy VT-20 (r_0 = 4,48 g/cm^3) was measured in the pressure range of 50÷150 GPa. It was obtained, that the values of sound velocities are reduced under the pressures higher ~130 GPa. If to take account for the fact that the obtained values are elastic longitudinal sound velocities, the supposition can be made that this break in values points to beginning of alloy melting in shock wave.

Conclusions

The data on sound velocities, which were obtained in this work by the optical method, are in good agreement with the available calculation results, as well as with experimental data of the other authors within the error limits. Additional researches are required for more precise determination of the melting area boundaries for the metals investigated in the work.

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