Homogeneity in a Metal Wire under Melting

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Results of numerical simulations of the melting wave in a tungsten wire heated by a high-power nanosecond current pulse are presented. To take into account the hydrodynamic effects under melting, a semiempirical multiphase equation of state for tungsten is used. The structure of the melting wave at different parameters of the heating is studied, and a theoretical evaluation for the thickness of this wave, $\delta_m$, is proposed. The homogeneity of the distribution of parameters over the wire can be expected in the case of $\delta_m \gg a_0$, where $a_0$ is the initial radius of the wire. The melting wave can be considered as a discontinuity of thermophysical properties of the solid and liquid phases at $\delta_m \ll a_0$.

KEY WORDS: equation of state; high-power current pulse; homogeneity; melting wave; thermophysical properties; tungsten; wire explosion.

1. INTRODUCTION

Fast heating of metal wires by a high-power current pulse is a common technique for investigations of thermophysical properties of liquid metals under high pressures and temperatures [1]. Parameters of the circuit and the heated wire are usually chosen so that the skin-layer thickness is greater than the initial radius of the wire. Therefore, one can assume that parameters of the specimen possess homogeneous radial distribution during heating of the wire. Melting of the wire is initiated at the outer boundary because the energy barrier of heterogeneous nucleation of liquid on the solid specimen surface equals zero [2, 3]. This phase transition does not have to lead to a...
1. INTRODUCTION

There are many problems in understanding the melting process under the influence of powerful fluxes of energy (see, for example, Refs. 4 and 5), but studies of the inner structure of the melting wave have not been carried out. Commonly the melting wave is considered as a discontinuity of thermophysical properties [6]. Nevertheless, it is reasonable to assume that the inner structure of the melting wave for the case of a small size specimen would be important. In this case the size of the specimen would be either comparable with or greater than the thickness of the melting wave. Under these conditions, it is necessary to take into account that a two-phase solid–liquid mixture in the melting wave should be described as a heterogeneous medium with effective properties.

Let us explain how we understand the idea 'melting wave.' This object has front and rear surfaces. The front of the melting wave is a boundary between the solid and two-phase solid–liquid mixture states of matter, whereas its rear surface is a boundary between the two-phase solid–liquid mixture and liquid states. The thickness of the melting wave, \( \delta_m \), is the distance between the front and rear surfaces; it can be much greater than the specimen size in the direction of the wave propagation.

For the case of melting of the wire heated by a large power current pulse, the nonhomogeneous distribution of parameters in the wire will be more marked for small values of the thickness, \( \delta_m \lesssim a_0 \), where \( a_0 \) is the initial radius of the wire. The distribution of parameters over the wire will be practically uniform during the melting process at \( \delta_m \gg a_0 \).

If the distributions of density and temperature over the wire are homogeneous, the pressure can be written as follows:

\[
P(r) = P(a) + \frac{1}{4} \mu j^2 a^2 \left(1 - \frac{r^2}{a^2}\right),
\]

where \( a \) is the wire radius, \( P(a) \) is the ambient pressure, \( \mu \) is the absolute magnetic permeability, and \( j \) is the current density.

Using the technique presented in Ref. 7, we can obtain for the melting temperature increase along the wire radius,

\[
\Delta T_m = \frac{1}{2} \left(\frac{dT_m}{dP}\right) \mu j^2 r dr,
\]

where \( \frac{dT_m}{dP} \) is the temperature difference versus pressure along the melting curve.