SOLIDIFICATION ON SURFACE

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Abstract: This article uses mathematical mathematical models of tasks by Stefan and Stefan-Schwarz describing the technologies of IMSCHA "Acad. A. Balevski ". Described are processes for solidifying a drop (droplet) over a surface of a metal substrate. Processes of solidifying of metal melts in the form of spheres having a radius of 50 nm are described. The temperature fields of the open thermodynamic system drop / substrate system are presented. The influence of the change of specific parameters from the hardening process is represented by the type of the temperature field of the OTS.

Keywords: Stefan and Stefan-Schwartz problem, drop (droplet) on the surface of substrate, temperatures curves

1. Introduction – основен процес

In Fig. 1 is shown the solidification on surface process:

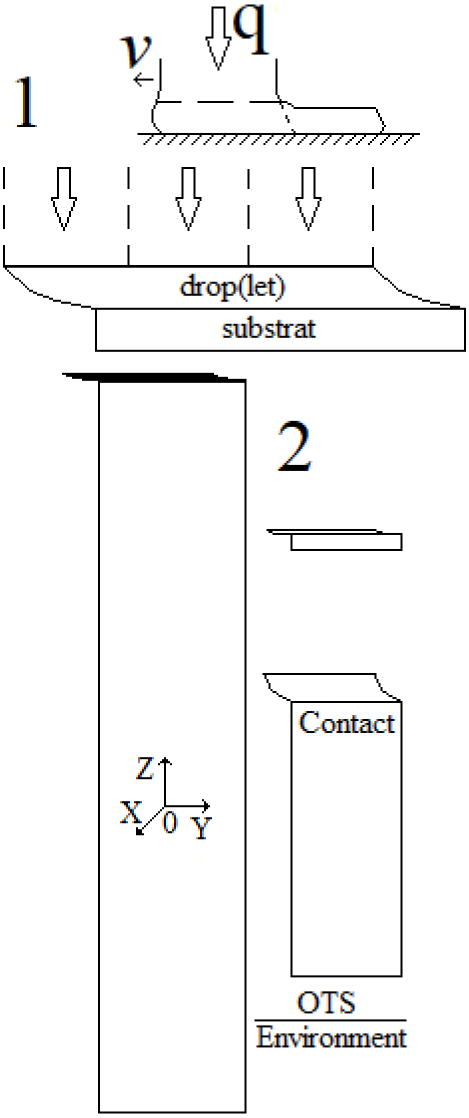
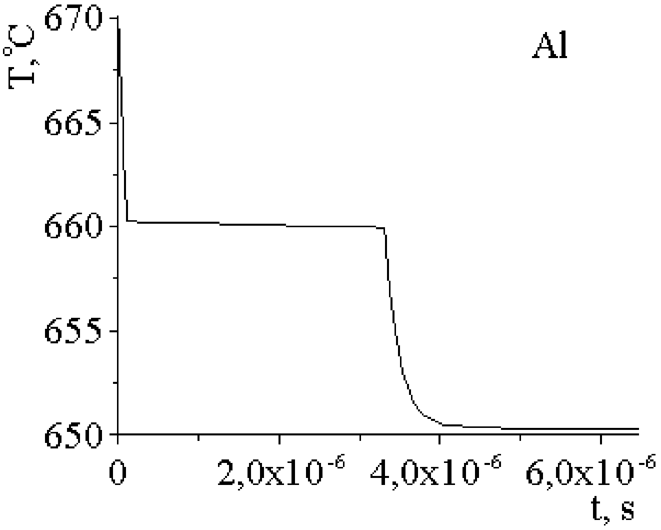
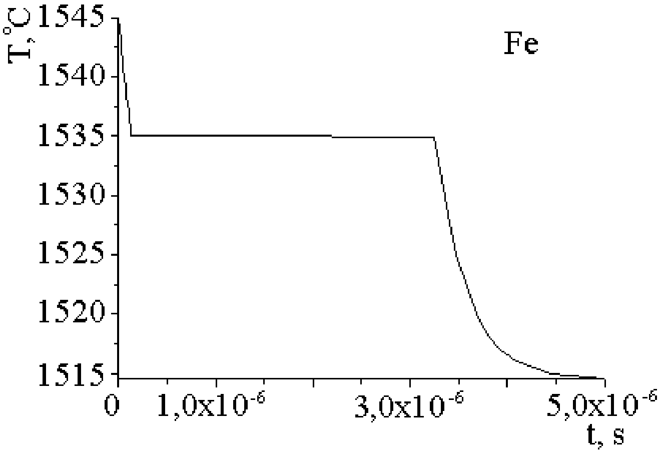


***Fig. 1** Geometric idea by cross section of the open thermodynamic system (OTS) – drop (let) solidification on surface of the substrate: 1 – Physics: drop and flow of melt, v and q are velocity and stream; 2 – different size of system.*

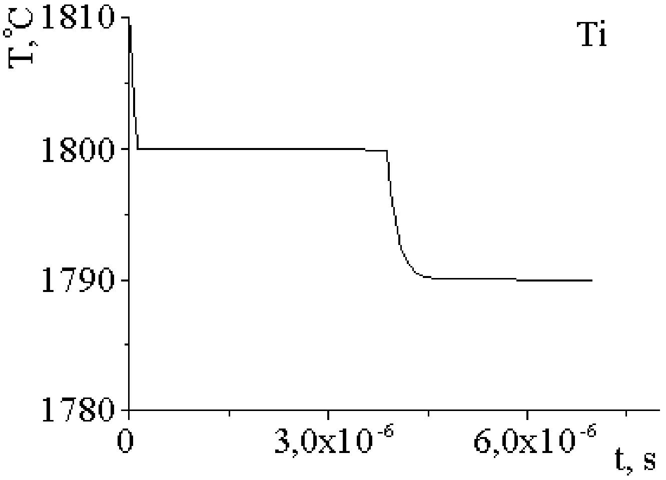
Figure 2 presents our results [20], supplemented by new ones. These are time-temperature curves of solidification of spheres of different materials with a radius R = 50 nm:



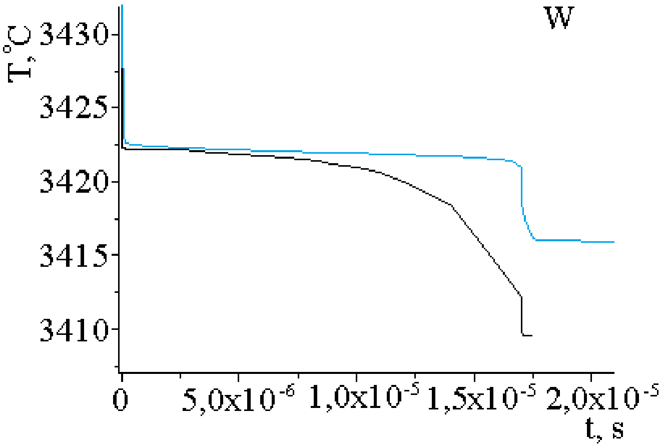
Pure Al: T_m = 660, 1 ^{o} C, latent heat of fusion at T_m is Q_m = 401,819 kJ/m^3, heat conductivity λ_S = 209 w/(m^3.K) λ_L = 104.675 w/(m^3.K), heat capacity c_S = 2540 kJ/(kg.K) c_L = 2380 kJ/(kg.K), density ρ_S = 2540 kg/m^3, ρ_L. = 2380 kg/m^3, index S – solid, index L –liquid;



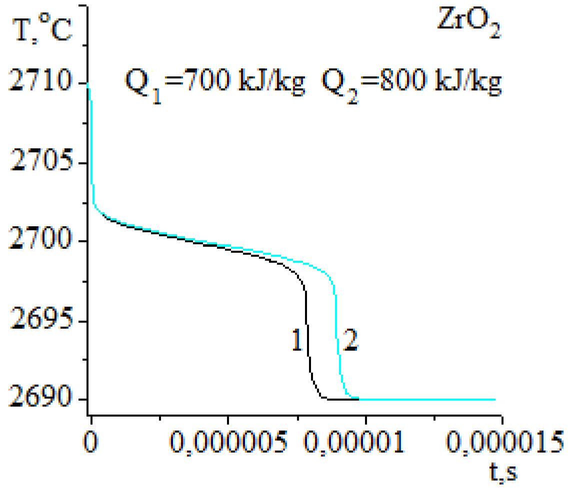
Pure Fe: T_m = 1535 ^{o} C, Q_m = 272 kJ/m^3, λ_S = 33 w/(m^3.K) λ_L = 29 w/(m^3.K), c_S = 447 kJ/(kg.K) c_L = 800 kJ/(kg.K), ρ_S = 7400 kg/m^3, ρ_L. = 7145 kg/m^3;



Pure Ti: T_m *= 1800 ° C,* Q_m *= 376,810 kJ/*m^3*, heat conductivity* λ_S *= 22.5 w/(*m^3*.K)* λ_L *= 18 w/(*m^3*.K), heat capacity* c_S *= 523 kJ/(kg.K)* c_L *= 628 kJ/(kg.K), density* ρ_S *= 4540,6 kg/*m^3*,* ρ_L*. = 4500 kg/*m^3*, index S – solid, index L –liquid;*



Pure W: T_m *= 3422 ° C,* Q_m *= 255,390 kJ/*m^3*,* λ_S *= 196 w/(*m^3*.K)* λ_L *= 76,2 w/(*m^3*.K),* c_S *= 150,7 kJ/(kg.K)* c_L *= 152,8 kJ/(kg.K),* ρ_S *= 19300 kg/*m^3*,* ρ_L*. = 19200 kg/*m^3*. Important: the difference between the two curves is due to the precision of defining the parameters of the mathematical model of the heat source in Stephen's task [].*



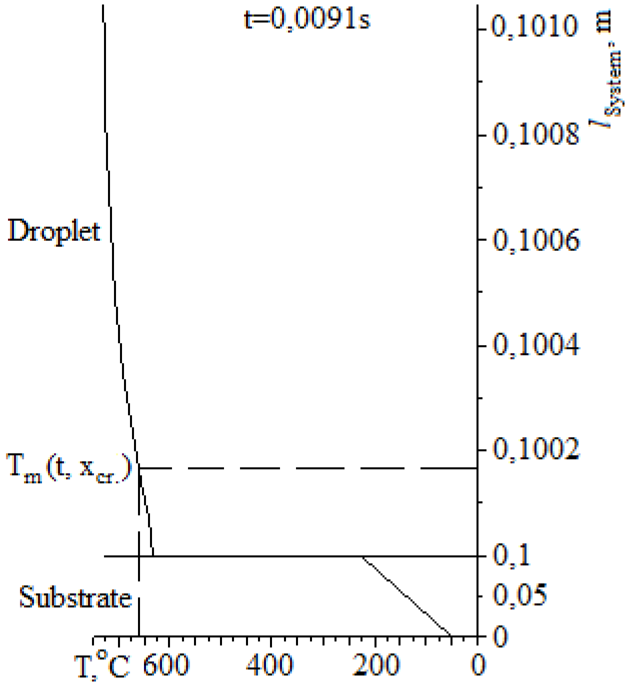
Material ZrO: T_m *= 2700 ° C,* Q_m *= 700 ÷800 kJ/*m^3*,* λ_S *= 1.95 w/(*m^3*.K)* λ_L *= 2.44 w/(*m^3*.K),* c_S *= 730 kJ/(kg.K)* c_L *= 730 kJ/(kg.K),* ρ_S *= 3300 kg/*m^3*,* ρ_L*. = 3200 kg/*m^3*; curve 1 -* Q_m *= 700 kJ/*m^3*; 2 –* Q_m *=÷800 kJ/*m^3 *[14].*

Fig. 2 *Solidification of different materials – spheres of different materials with a radius R = 50 nm.*

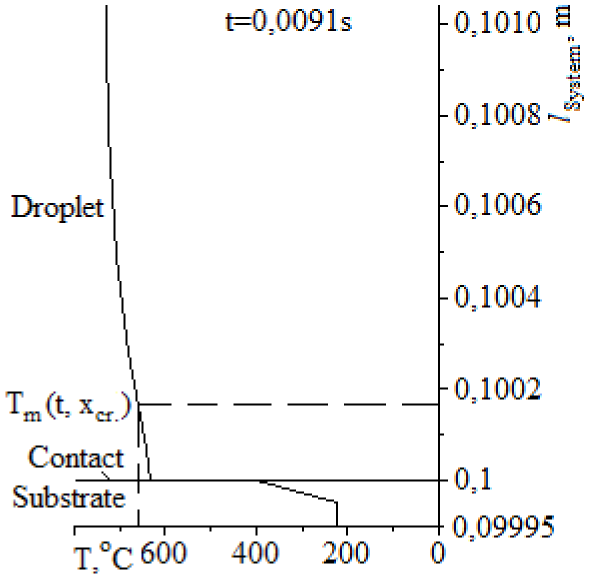
Mathematical models are based on the tasks of Stefan and Stefan-Schwarz, created and realized through non-commercial software products at IMSETCHA "Acad. A. Balevski "BAS [2, 3, 4, 5 and 6]. The process of solidification (phase transition of first order) is fundamental in material science for obtaining structures bearing different working properties of the respective materials [1, 6]. The aim of this work is the calculation process of solidification a drop on different sizes on the surface of a metal substrate.

2. Numerical solutions - Stefan-Schwarz tasks

In Fig. 3 are introduced solidification temperature field by Finite elements method (FEM) of this task (see Fig.1):



Stefan-Schwartz temperature field: The geometry space of FEM is 3D but the temperature task in the direction of axis 0Z is 1D;



Important: ccontact heat exchange with the temperature difference at the surface of the drop-substrate contact;

Fig. 3 *Stefan-Schwartz temperature great OTS with size (substrate* x_{max}*=0,02,* y_{max}*=0,02,* z_{max}*=0,1) [m] and (drop* x_{max}*=0,02,* y_{max}*=0,02,* z_{max}*=0,00105) [m].*

The results of Fig. 3 present the possibilities of computational mathematics and physics of non-stationary field of solidification (phase transition of first order) on a macro-scale. The technological parameters of the phase transition of first order i.e. the process of formation of the polycrystalline structure on a macro-scale.

The technological parameters of the hardening process are known for a long time or for the phase transition of the first generation. We choose the parameter: the initial temperature field of the corresponding OTS T(x, y, z, t = 0) and the coefficient of heat transfer at the contact surface α_c (see Fig. 1 and Fig. 2). In Fig. 4 we present the influence of these two parameters on the temperature field of the drop only:

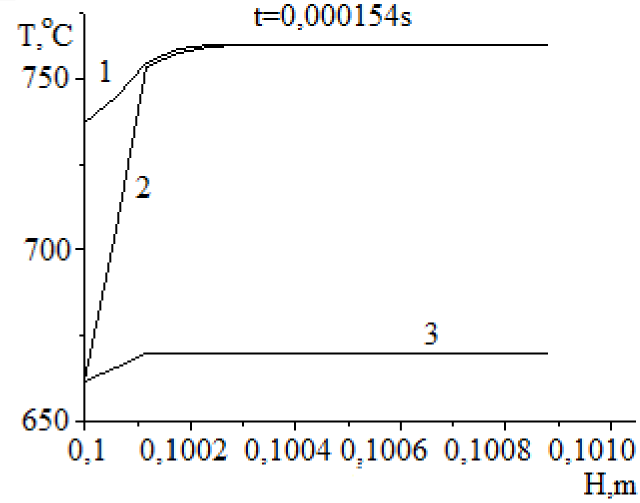


Fig.4 *Comparative analysis by the type of temperature field only at the drop by changing* ***the initial melt temperature*** *and by changing the* ***coefficient of contact heat transfer****:* $T_{drop}(x,y,z,0) = 760$, ***1*** *°C,* $\alpha_c = 56000\ w/m^2s\ ^oC$; ***2*** $T(x,y,z,0) = 760{,}1\ ^oC$ $\alpha_c = 560000\ w/m^2s\ ^oC$; ***3*** $T(x,y,z,t=0) = 670{,}1\ ^oC$ $\alpha_c = 56000\ w/m^2s\ ^oC$.

From Fig. 4 clearly shows the influence on the type of the temperature field at time t = 0 0091s.

The thermophysical properties of the substrate have a definite effect on the phase transition of first order. For this reason, the following figures shows the influence of the temperature field in the droplet and the substrate in a small OTC with dimensions (x_{max} = 0,00002 m, y_{max} = 0,00002 m, $_{zsubstrate\ max}$ = 0,1 and $z_{droplet}$ = 0,00105 m):

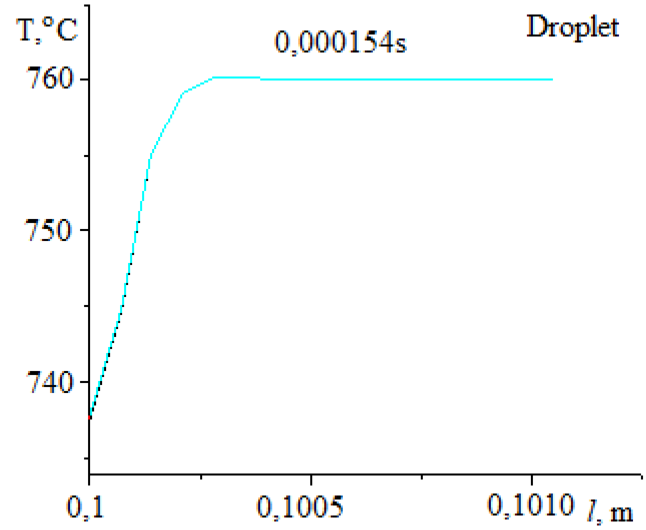


Fig. 5 *Temperature fields of the droplet at time t = 0.000154s steel (black line) and aluminum (blue line) substrates. Initial conditions are:* $T_{drop}(x, y, z, 0) = 760$, ***1*** *°C,* $\alpha_c = 56000\ w/m^2s\ ^oC$; ***2*** $T(x, y, z, 0) = 760{,}1\ ^oC$. *The minimal effect is very clearly seen even at start time t = 0,000154s.*

Here, we note that the thermophysical parameters of the substrate are part of the macro-level influence parameters.

Important: Your own substrate is related to modern technology called 3DPrinter.

On the following figure 6 presents a comparative analysis of the temperature fields of the OTC in substrates with different heat-physical properties (aluminum and steel substrates):

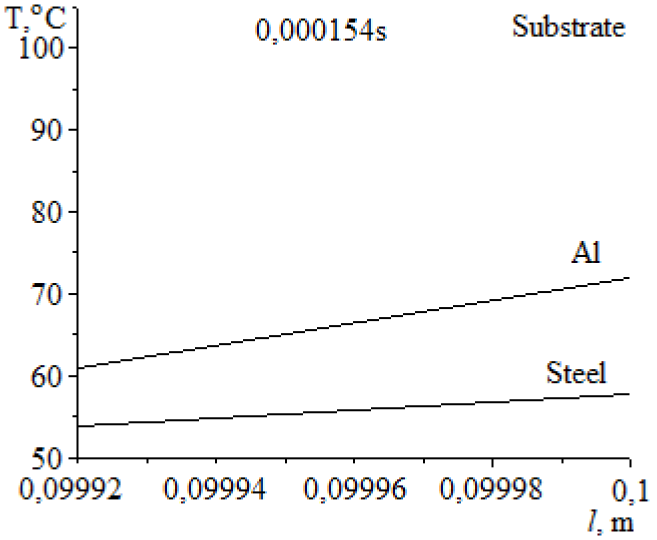


Fig. 6 *Comparative analysis of temperature fields in substrates with different thermophysical properties in the case of Al and Steel. Initial conditions are:* $T_{drop}(x, y, z, 0) = 760$, ***1*** *°C,* $\alpha_c = 56000\ w/m^2s\ ^oC$; ***2*** $T(x, y, z, 0) = 760{,}1\ ^oC$. *The minimal effect is very clearly seen even at start time t = 0,000154s.*

From Fig. 6 shows the significant difference with the direct relationship to the contact heat exchange, namely the influence of the surface temperature of the contact substrate/droplet.

The results obtained relate to different technological processes. Stefan Schwarz's main task allows him to develop as a connecting task with mathematical and mathematical physics tasks. The latter are related to lower levels. These ideas have been developed in various studies by many authors.

Stephen-Schwartz's task is the natural aggregate mathematical approach to describe technological processes in phase transitions of first and secondary order. Material science has evolved as an interdisciplinary field of study [7, 8, 9 and 10]. The next figure presents the multi-scale linking possibility of heat conduction theory and mathematical modeling [2, 3, 4, 5, 6, 11, 12 and 13]:

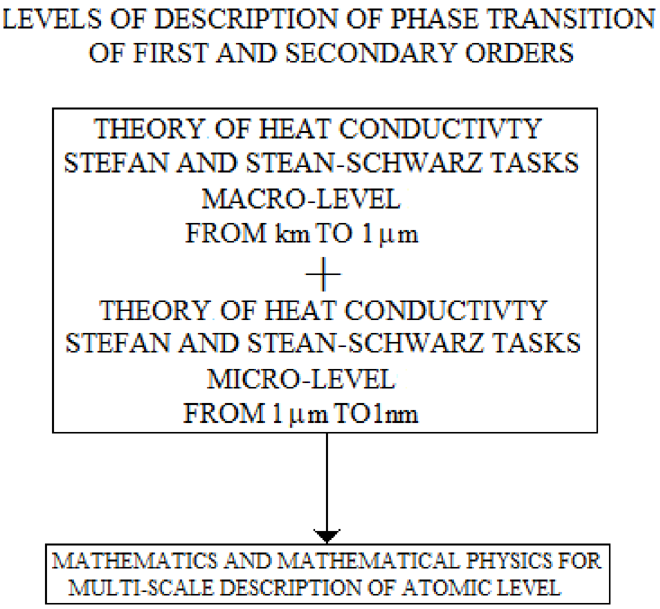


Fig. 7 *Multi-scales description of phase transition of first and secondary orders by Stefan-Schwartz tasks + Mathematics and mathematical physics.*

According to the principles of material science [7, 8, 9 and 10] and mathematical modeling [2, 3, 4, 5, 6, 11, 12 and 13], a methodology for Basic Knowledge is proposed: Methodology for Basic Knowledge is proposed: 1. General evaluation of the structure (on the meso-level) and the properties of the material; 2. Select a section of mathematics and mathematical physics for multi-scale description; 3. A specific mathematical model of the structure, with the working properties, the technological process, the work and the life of the material. A very important point is the use of this methodological frame work for the additive capabilities of the 3Dprinter [15, 16 and 17] technology i.e. *3Dprinter interaction with die casting and heat treatment*. 3Dprinter + die casting + heat treatment are an essential task of Industry 4.0 [1]. Mathematical modeling in Industry4.0, in our view, is close to pure mathematics [6]. Such an assumption canal so be accepted on the basis of works [2, 3, 4, 5, 6, 11, 12, 13, 18 and 19]. The 3Dprinter technology has a great application (from food, medicine and weapons) and is an incentive for its mathematical modeling [17 and 18].

Additive manufacturing AM [15] is a concept that covers: casting, separation of metal turning, milling, plastic deformation, welding, forging and electroerosity processing heat treatment. But at the end of the 20th century new technologies for depositing materials such as micro-casting [21] and spraying were developed at Stanford University and Carnegie Mellon University [22]. 3DPrinter modifies the AM concept by expanding its idea of sequentially adding and linking material sequentially, following a three-dimensional profile of the blank, with automated control [15].

Significant results have been achieved with 3D printer technologies [23, 24 and 25]. The reason for the powerful entry of a 3D printer is the good price that falls great convenience to work with full control of the technology. This makes the 3D printer actually leading the Industry 4.0 revolution [1].

3. Conclusions

The obtained results represent the broad application of Stefanov type tasks in macro and nano-scale areas.

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