SOLIDIFICATION ON SURFACE

Ass. Prof. Eng. St. Bushev PhD.1, Ass. Prof. Eng. I. Georgiev PhD.2
Bulgarian academy of sciences
1 Institute of Metal Science, Equipment and Technologies With Hydro- and Aerodynamics Center „Acad. A. Balevski”
Sofia 1574, 67 „Shipchenski prohod” blvd. Bulgaria
2 Institute of Information and Communication Technologies „Acad. G. Bonchev” str. bl. 2 Sofia 1113 Bulgaria
and
2 Institute of Mathematics and Information Technologies „Acad. G. Bonchev” str. bl. 8 Sofia 1113 Bulgaria
stbushev@abv.bg, ivan.georgiev@parallel.bas.bg

Abstract: This article uses mathematical mathematical models of tasks by Stefan and Stefan-Schwartz 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.](image)

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:

**Al**

Pure Al: $T_m = 660 \, ^\circ C$, latent heat of fusion at $T_m$ is $Q_m = 401,819 \, kJ/m^3$, heat conductivity $\lambda_S = 209 \, w/(m^3.\,K)$, heat capacity $c_S = 2540 \, kJ/(kg.\,K)$, density $\rho_S = 2540 \, kg/m^3$, $\rho_L = 2380 \, kg/m^3$, index $S$ – solid, index $L$ – liquid;

**Fe**

Pure Fe: $T_m = 1535 \, ^\circ C$, $Q_m = 272 \, kJ/m^3$, $\lambda_S = 33 \, w/(m^3.\,K)$, $\lambda_L = 29 \, w/(m^3.\,K)$, $c_S = 447 \, kJ/(kg.\,K)$, $c_L = 540 \, kJ/(kg.\,K)$, density $\rho_S = 7400 \, kg/m^3$, $\rho_L = 7145 \, kg/m^3$. 

---

33

YEAR II, ISSUE 1, P.P. 33-36 (2018)
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](image)

**Material** ZrO: $T_m = 2700 \, ^\circ C$, $Q_m = 700 + 800 \, \text{kJ/m}^3$, $\lambda_S = 1.95 \, \text{w/(m.K)}$, $\lambda_L = 2.44 \, \text{w/(m.K)}$, $c_S = 240 \, \text{kJ/(kg.K)}$, $c_L = 3300 \, \text{kJ/kg}$, $\rho_S = 3200 \, \text{kg/m}^3$, $\rho_L = 600 \, \text{kg/m}^3$; curve 1 - $Q_m = 700 \, \text{kJ/m}^3$; 2 - $Q_m = 800 \, \text{kJ/m}^3$ [14].

**Fig. 2** Solidification of different materials – spheres of different materials with a radius $R = 50 \, \text{nm}$.

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.
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 \( \alpha_c \) (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:

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 (\( x_{\text{max}} = 0.00002 \) m, \( y_{\text{max}} = 0.00002 \) m, \( z_{\text{substrate max}} = 0.1 \) and \( z_{\text{droplet}} = 0.00105 \) m):

From Fig. 4 clearly shows the influence of the type of temperature field at time \( t = 0.0091s \).

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]:

**LEVELS OF DESCRIPTION OF PHASE TRANSITION OF FIRST AND SECONDARY ORDERS**

![Fig. 7](image-url)
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.

4. References

15. 3DPrinter www.etiket.bg/bg/news-view/40.html
16. 3D printers for direct printing in metal (In Bulgarian) www.spacecad.bg/printeri-za-metal
18. I. Akinola, Modelling the Stereo-lithography Process, Electrical Engineering, Stanford University, iakinola@stanford.edu
19 A. Anastasiou at al., 3D Printing: Basic concepts Mathematics and Technologies... - Semantic Scholar, https://pdfs.semanticscholar.org/.../7486320e82081935ac20bc...
25. www.geomedia.bg/.../5251--airbuse--with-first-in-the-world-airplane-printed-of-3d-pr...