INTENSITY OF SOLIDIFICATIONI

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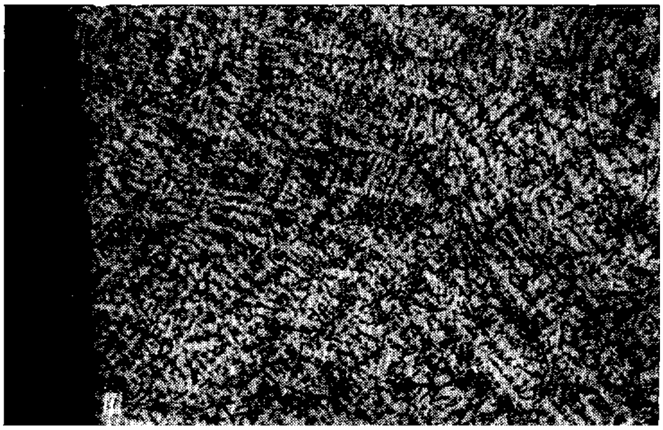
Abstract: *The identification of the heat exchange intensity at the work surface of the mold is defined by the base information of the type and movement of the solidification front. Parameters and their influence are shown on the type and movement of the solidification front: initial melt temperature; initial temperature of the mold; the ceramic coating on the work surface of the mold; distribution of the mass of the mold. The methodological link of these parameters is shown in the creation of each casting technology.*

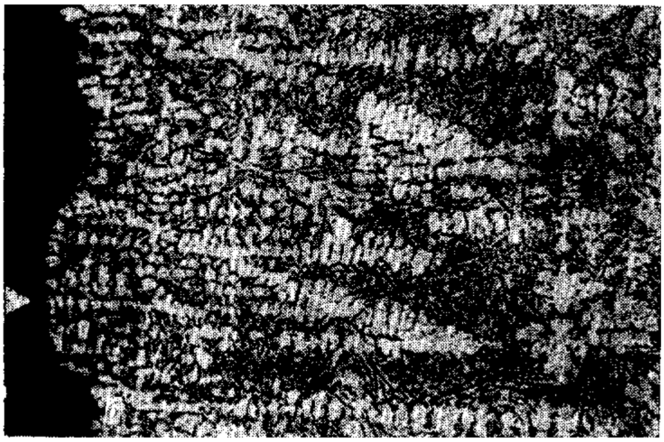
Keywords: Heat transfer intensity identification, parameters, methodology, technological regime of solidification.

1. Introduction

At work [1] an experimental indirect method for estimating the thermo-resistance and thickness of the ceramic coating of the working surface cast/(metal mold) in a cyclic casting process according to the following methodology: 1. Recorded with thermocouples non-stationary temperature field in the formation of cylindrical castings; 2. A 1D thermo-elastic model [2] is used to describe the non-stationary temperature field of solidification; 3. Time-temperature curves in the mold are used to estimate the thermo-resistive casting/(metal form); 4. Very important information is also the type of structures at the surface of the casting. On Fig. 1 these structures are presented [1]:



a) Without ceramic coating $\alpha(0) = 4932$ w/m^2 K;



b) With fresh ceramic coating $\alpha(0) = 2174$ w/m^2 K;

c) Worn ceramic coating $\alpha(0) = 3164$ w/m^2 K

Fig.1 *Структури при повърхност на цилиндрична отливка [1] и идентифицирани коефициенти на топлопредаване при границата отливка-(метална форма) в началният момент от време t=0 sec: a) – без керамично покритие $\alpha(0) = 4932$ w/m^2 K; b) – със свежо керамично покритие на работната повърхност на металната форма $\alpha(0) = 2174$ w/m^2 K; c) – износено керамично покритие $\alpha(0) = 3164$ w/m^2 K.*

On the basis of the methodology [1 and 2], modern software can be used to solve the non-stationary temperature field in the case of solidification by Stefan-Schwarz 3D task. In our institute, non-commercial software products have been created.

Here is used a software product was created and developed by M. Dimitrov and S. Bushev for numerical solution of Stefan-Schwarz's 3D task by Finite Elements Method (FEM). The methodology of [1 and 2] is developed by numerical representation of the solidification process – a first-order phase transition as follows: 1. The numerical 3D task of Stefan-Schwarz in cylindrical geometry is solved; 2. The most important is the representation of the movement of the solidification front; 3. The heat transfer coefficients identified at the boundary casting/(metallic form) of [1] (see Fig. 1) are used; 4. A technological regime of motion of the hardening front is created.

The aim of this work is to obtain a technological mode of consolidation through the influence of: 1. the initial thermo-resistance of the work surface casting-(metal mold); 2. The initial temperature field of the metal mold; 3. Initial temperature of the metal melt; 4. Distribution of the mold mass.

2. Receive technological regime of phase transition from the first order in casting.

3.1 Comparative analysis of the solidification process at different initial thermal-resistances at the border casting - metal form.

In Fig. 2 is a comparative analysis of the solidification with a heat transfer coefficient *without ceramic coating* $\alpha_{C/M}(0) = 4932$ w/m^2 K and *with a fresh ceramic coating on the work surface of the metal mold* $\alpha_{C/M}(0) = 2174$ w/m^2 K (see Fig. 1).

The numerical experiment does not account of the fill process. The cast is of pure aluminum with thermal coefficients of cast – melt (m) heat conduction $\lambda_m = 209$ w/m K, heat capacity $c_m = 1149$ J/kg, density $\rho_m = 2380$ kg/m^3 and solid phase (s) $\lambda_s = 228$ w/m K, $\rho_s = 2500$ kg/m^3, $c_s = 1279$; steel mold $\lambda_{mold} = 54{,}28$ w/m K, $\rho_{mold} = 7900$ kg/m^3 $c_{mold} = 486$ J/kg. Temperature melting point of pure Al is $T_m = 660{,}1\ ^oC$ and latent heat of melting is $Q_L = 408020$ J/m^3. The initial temperature of melt is $T_C = 720\ ^oC$ and the temperature of mold is $T_M = 218\ ^oC$. The thermal coefficients of heat transfer at boundary cast/mold are shown above.

It is well known that the thermal resistance of the cast/mold boundary in during the actual casting process. We choose constant thermal resistance i.e. constant heat transfer coefficient for numerical experiments.

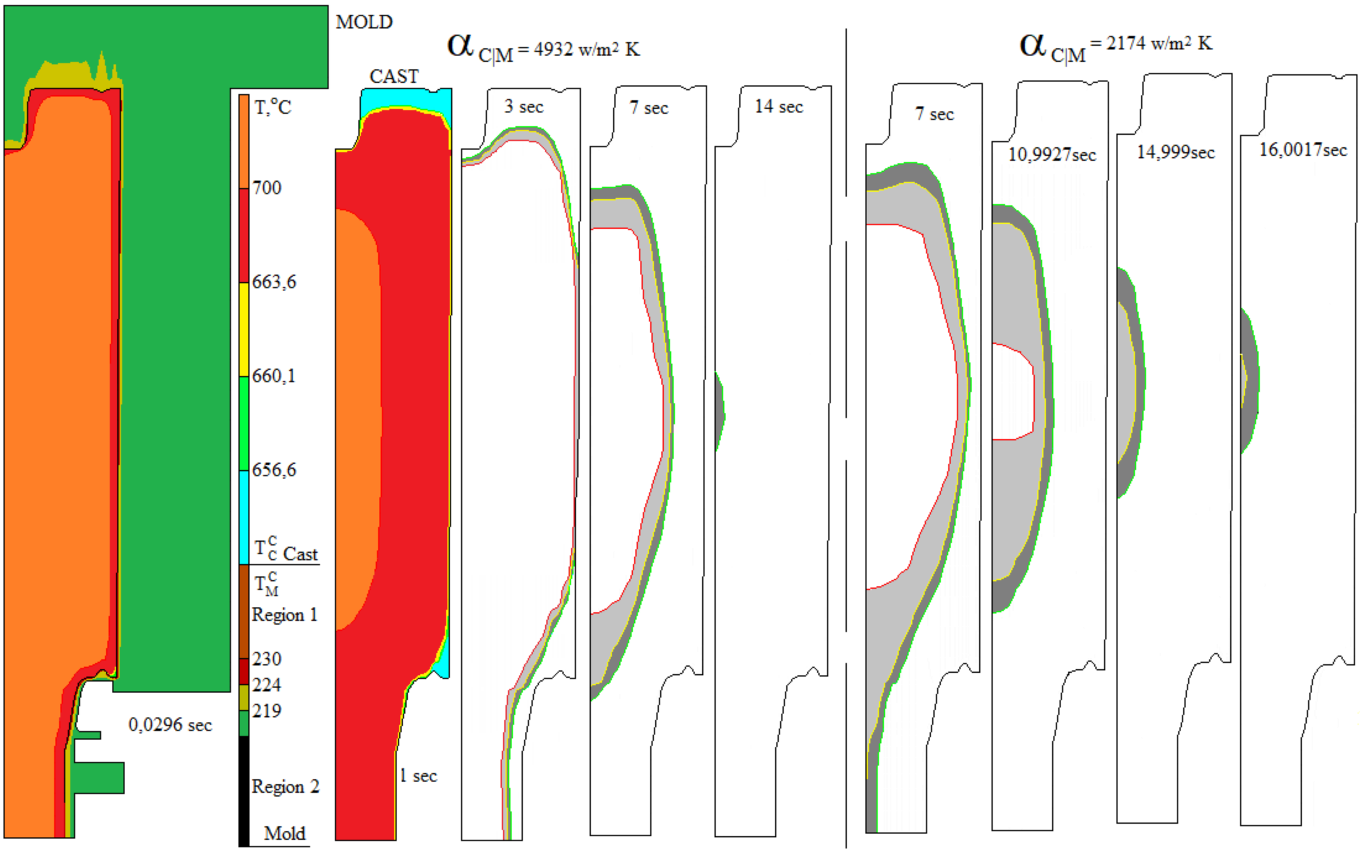


Fig.2 *Geometry view of thermodynamics system. Comparative analysis in* ***free regime of solidification*** *with different coefficients of* ***thermal-resistances*** $\alpha_{C/M}(0) = 4932$ *w/m² K and* $\alpha_{C/M}(0) = 2174$ *w/m² K at the work surface cast/(metal mold). Contact temperatures of cast* T^C_C *and mold* T^C_M *at the cast/(metal mold) boundary. Regions 1 and 2 are important interest – Impact of boundary conditions of the mold.*

The temperature field of the thermodynamic system at successive moments of time are as follows: at thermal-resistance $\alpha_{C/M}(0) = 4932$ *w/m² K*

t = 0,0296 s is the temperature field of the whole cast/mold system; t = 1s obtaining closed isotherm lines; t =3 s open solidification front; t = 7 s obtaining of closed melt metal liquid area; t = 14 s end of the solidification process;

at thermal-resistance $\alpha_{C/M}(0) = 2174$ *w/m² K*

t = 7 s closing time and formation of a closed melt metal liquid area; t = 10,9927 s closed area and naturally non-filling with liquid metal; t = 14,999 s solidification of the melt in the closed area; t = 14 s end of the solidification processin the closed zone;

The heat transfer coefficient of the form surface 4932 w/m² K is a real value because the shape surface of the form is not processed for a higher heat transfer coefficient. The value 4932 w/m² K is much lower than the maximum possible values of 40,000 (or the theoretically possible value of 56,000 [5]). The coefficient of thermal conductivity of the coating used in work [1] is obtained in the range of 0,22÷0,25 w/m K. A ceramic coating with this thermal conductivity coefficient defines a value of 2174 w/m K by the ratio $\lambda_{Ceramic\ coting}/\delta$*, where* δ *is where* δ *is the thickness of the ceramic coating.*

In the free solidification regime, closed melt zones are always formed, creating macro and micro-structural defects. It is not possible to supply these areas with liquid metal.

Filling the shape cavity is from the bottom (see Fig. 2). This is the only place to enter the fresh melt, i.e. the end of the metal pipe is also in the role of the "dead head". It follows that the solidification regime to be "technological" is necessary in such cases to be opened to the melt inlet. On Fig. 3 we present a technological regime of solidification by: Different constant coefficients of heat transfer on the cast/(metal mold) boundary; different initial temperature; mass distributed of the mold

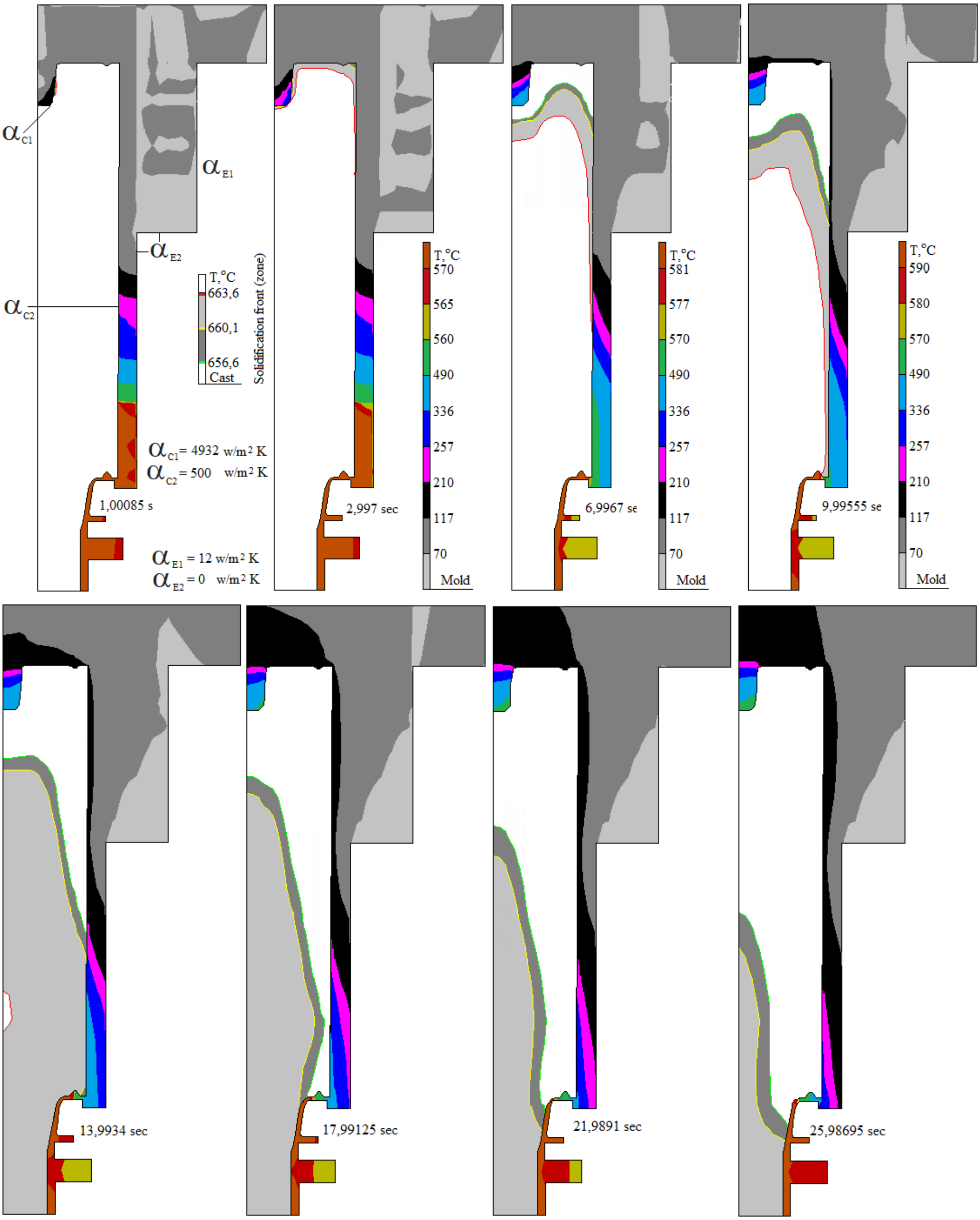


Fig. 3 *Technological regime of solidification by: 1. Different coefficients of heat transfer at the cast/(metal mold) boundary α_{C1} 4932 w/m^2 K α_{C2} = 500 w/m^2 K and at mold/environment boundary α_{E1} = 4932 w/m^2 K α_{E2} = 0 w/m^2 K; 2. Initial temperature of metal melt is T = 777 ^{o}C. Three different initial temperature of the mold 570 ^{o}C, 257 ^{o}C, 70 ^{o}C; 3. Mass distributions of the mold. The solidification process we introduced by solidification zone [663,6÷660,1÷656,6]. Technological solidification regime is obtained. Up to a point in time of 9.99555 sec, the hardening zone is open to the hottest part of the thermodynamic system. At a time of 13.9934 sec, the isotherm line T = 663.6 ^{o}C closes, but the remainder of the hardening zone remains open to the hot end. It is important to note that the solidification zone until the end of the numerical experiment is kept open (see the next Fig.4).*

Figure 4 shows the end of our numerical experiment

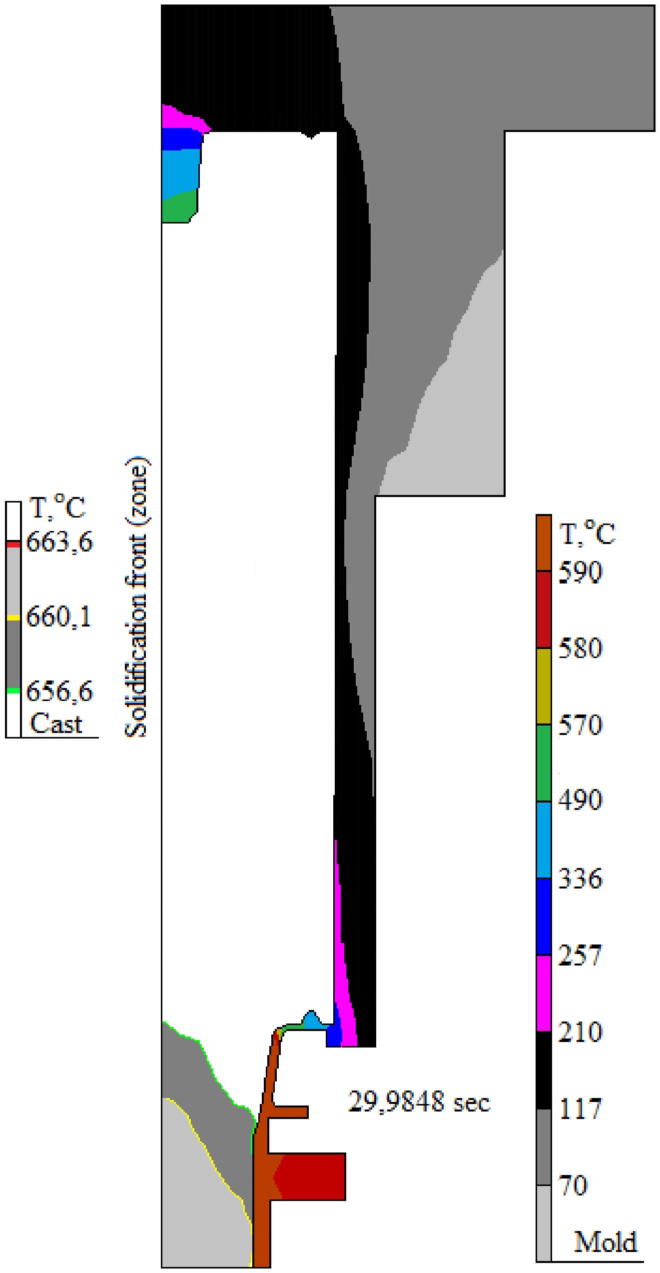


Fig.4 *The end of the numerical hardening experiment is the entry of the open solidification zone into the metal conduit.*

3. Material Science – phase transitions, structures.

It is well known that the heat exchange rate influences the local conditions of polycrystalline structure formation by the local solidification time (LST) along with the local crystallization time (LCT). It is assumed that LST ~ LCT. The ultimate casting structure is most often obtained after heat treatment [3 and 5]. DAS and SDAS analyzes determine scales that work: SDAS → 40,17 µm and

$$LST \sim LCT = (SDAS/10)^3 \text{ sec.} \quad \text{(SDAS)}$$

In Fig. 5 is a specific microstructure of casting after curing for which $LCT = (SDAS/10)^3$ sec $= (40{,}17/10)^3 = (4{,}017)^3 = 64{,}819472913$ sec. This value is decisive for the type of heat exchange intensity in the foundry process. The presented methodology in this article specifies precisely separate stages for estimation of important foundry parameters of the phase transitions of first and second order i.e. the macro-level micro level relationship or the relation micro-structure → properties [3, 4, 5, 6].

The idea of scale from this point of view is in Fig. 5

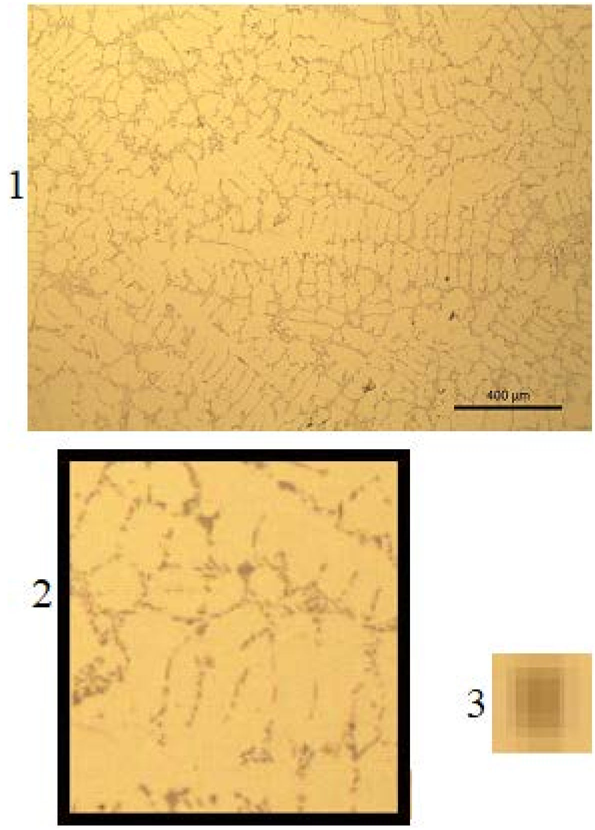


Fig. 5 *Scals: 1 micro-structure 400 µm DAS; 2 SDAS; 3 pixel – min.*

The identification of heat exchange [1, 2 and 7] allows the question of a multi-dimensional description from the classical [3 and 5] to meso-level [4].

4. Conclusions

The presented methodology shows: The identification of the intensity of the heat exchange during casting is a constructive stage in the creation of each casting technology. The type and movement of the solidification front is basic information and control design.

5. Reference

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