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Simulation of solidification process for composite micro region with incomplete wetting of reinforcing particle

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Abstract: The article contains solidification kinetics comparison for micro regions containing hypothetical sphere particle with surface wetted in 100 and 90% of its area. Investigated material was the AlSi-SiCp composite with the same content of reinforcement (10%) for both cases. The composite was examined for temperature distribution, thermal gradient and solidification rate. For both components – matrix and reinforcement – the initial temperature was assumed as $T_R = T_M = 993$ K. Regions of structural discontinuity were assumed to be spherical gas spaces with minimal thickness distributed uniformly on sphere particle surface.

Keywords: Casting, Composite, Wetting, Solidification, Simulation

1. STATE OF INCOMPLETE WETTING OF REINFORCEMENT PARTICLE

State of incomplete wetting is obviously very undesirable but can occur in industrial processes. Surface without wetting can exceed half of the entire particle area causing states intermediate between coalescence and flocculation. In heat processes occurring in composites gas discontinuities are regions with diametrically different properties from all other technological components of the composite. Trying to classify composite components in respect of its decreasing heat conductivity we obtain: alloy matrix, ceramic reinforcement, and transition zone phases. Gas discontinuities in transition zones are the maximal possible heat resistance. Assumed content of these discontinuities of 10%, although with minimal thickness, is probably the case corresponding to defective industrial processes.

2. SIMULATION CONDITIONS

As most important from technological point of view the case of composite components with the same initial temperature was examined. In general analysis such system represents the smallest changes of investigated parameter amplitudes in temperature range and solidification interval. In figure 1 the gas discontinuities taken to analysis are shown; they are represented as round flattened spherical air blisters. Minimal thickness is imposed by calculating system and has a value of double number of layers and cell angles of 4°.

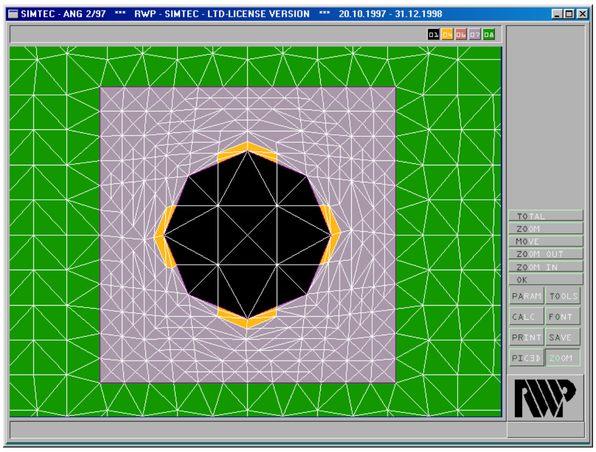


Figure 1. Geometry of the micro region containing air blisters in boundary zone

In studied central cross sections 11 virtual thermocouples were placed to record the temperature changes in solidification range of matrix cube region. Measuring points were located uniformly along the heat axis – on one of the main heat flow direction. Origin of coordinates was located in center of the particle. Three – dimensional heat flow was assumed. The matrix surroundings was the material with averaged properties of matrix and particles representing the thermo physical properties of modeled composite region containing 10% of SiC reinforcement. Simulation was conducted with use of FEM implemented in Simtec RWP system [1].

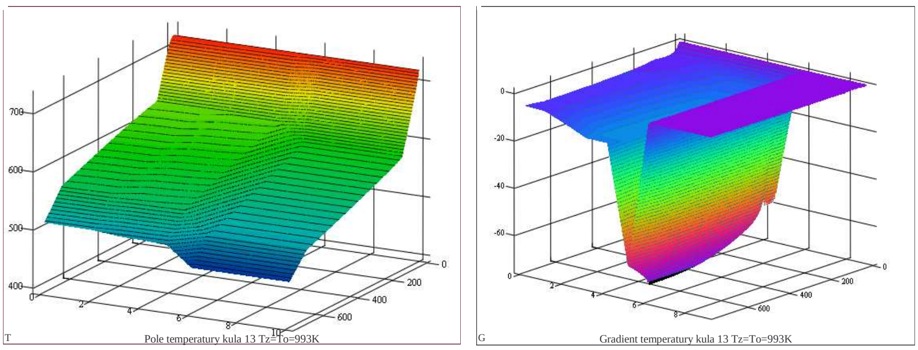
During the geometry modeling procedure the scale of similarity with $k=10^3$ was used and following proportions were used:

- matrix cube edge length 5,28 [cm]
- sphere particle diameter 3,04 [cm]

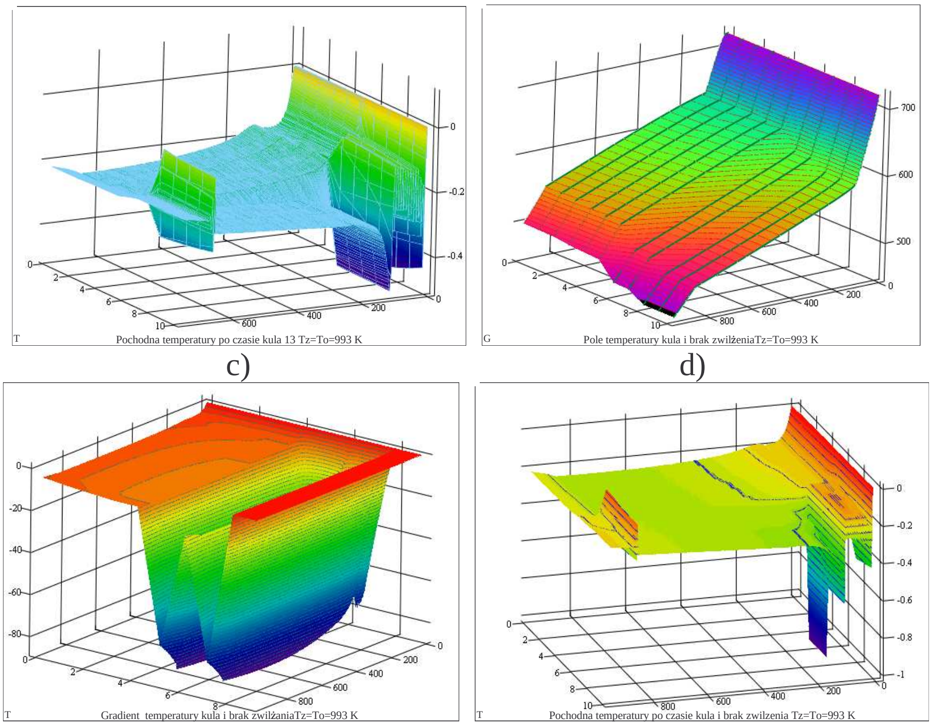
Initial thermal conditions for reinforcement, matrix, surroundings and the air were as follows: 300, 720, 720, 25 [°C]. Simulation was conducted with use of thermo physical data from the database of the program.

3. RESULTS AND DISCUSSION

Results of conducted simulation are shown on diagrams in figure 2. From the sixth point on direction coordinate the reinforcing particle begins.



a) b)



c) d)

e) f)

Figure 2. Diagrams of temperature changes T [^{o}C], thermal gradient dT/ds [K/cm] and temperature derivative dT/dt [K/s] in function of solidification time and heat flow direction f(l, t) [x 0,176 cm], [s]. Origin of the coordinate system is located in the center of reinforcing particle. a) – c) sphere particle with full wetting, d) – f) sphere particle wetted in 90%, on the f) figure the temperature derivative reaches the value of 2 [K/s], to make the diagram clearer ordinate axis was cut on 1 [K/s] level

The particle acts as a heat store. On the matrix side the gradient is negative (–0,2 ÷ –0,5) [W/cm*K], near the particle boundary breaks down to value of –78 [W/cm*K] (gradient minimum). Gradient inside the particle gets the value of about –5 [W/cm*K] and passes into the boundary zone more gently than in the matrix. On the derivative temperature diagram after time you can see the characteristic changes for solidification range, but more important the considerably larger amplitude of local extreme points in the matrix, which near the liquidus value pass into the particle. Rate of the temperature changes [K/s] in the particle is close to the rate of changes in the matrix. In the range of the solidification the rate in the matrix is almost equal to 0 (–0,1 [K/s]), while in the particle it reaches the local maximum in liquidus temperature and then decreases. In incomplete wetted particle system the decrease of temperature occurs later when the difference between components temperature is higher. This results with grater thermal gradient of about 12% (figure 2 b and e). In the center of air blister the local heat retardation occurs. In this region temperature changes are the slowest. On the gradient diagram we experience a skip from extreme value to nearly 0 value. Two different regions seen here determine the two materials with different thermal conductivity. Gradient value follows a pattern where it decreases nonlinear with temperature decrease and reaching the minimum just before the solidus temperature. The air blister causes a heat flow retardation and local heat incubation. The solidification interval increases of about 31% in relation to system with full wetting. In case of different initial temperature of the components the solidification interval is 20 times longer with full wetting and 28 times longer than in the studied case of the same temperature of the components (and full wetting). The corresponding values are indicated in table 1.

Table 1.
Characteristic relations of solidification interval for composite AlSi-SiCp at different initial temperatures of the components

	System	Solidification start	Solidification end	Solidification interval $\Delta t=(t_l-t_s)$	solidification intervals ratio
	Sphere particle:	[s]	[s]	[s]	[1/1]
1.	$T_R<T_M$ full wetting [2]	15	42	27	Poz. **2/1**: 20,4
2.	$T_R=T_M$ full wetting	100	650	550	Poz. **3/2**: 1,31
3.	$T_R=T_M$ incomplete wetting	100	850	750	Poz. **3/1** 27,8
	Tetrahedron particle				
4.	$T_R<T_M$ full wetting [2]	13	35	22	Poz. **3/4** 34,1

4. CONCLUSIONS

- Occurrence of incomplete wetting regions is harmful because it generates higher gradient values in boundary regions before the matrix reaches the liquidus temperature (about 12%) and causes greater temperature decrease rates.
- Compared to tetrahedron particle with full wetting it was found that solidification time could be increased of 34%.

Shape of carborundum particles is morphological close to the tetrahedron model particle [3], because the heat exchanging surface relation to unit of volume storing the heat is similar for tetrahedron and real carborundum particle. Reduced size of interfacial surface is also a cause of heterogeneous nucleation reduction. Thus the incomplete wetting favors the coarse grain macrostructure. Significance of parameters influencing the solidification interval is as follows: initial temperature of components, wetting quality (if it is close to 100%) and the particle shape.

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