Achievements in Mechanical and Materials Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology

16th - 19th May 2005
Gliwice-Wisla, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND

13th INTERNATIONAL SCIENTIFIC CONFERENCE ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

Simulation of composite micro regions solidification process

M. Cholewa

Foundry Department, Institute of Material Engineering and Biomaterials,
Faculty of Mechanical Engineering, Silesian University of Technology,
ul. Towarowa 7, 44 – 100 Gliwice, Poland, sekrmt3@zeus.polsl.gliwice.pl

Abstract: In this article author has compared solidification of different composite microregions containing only one reinforcing particle of regular solid shape and volume of 10% the matrix content. Compared was the temperature gradient and the solidification rate of the AlSi-SiCp composite at changeable contact surface of the components and changeable surface to reinforcing particle volume ratio (M_m). The temperature of particle and the matrix was set as non-equal ($T_r<T_m$).

Keywords: Casting, Composite, Dispersion, Solidification, Simulation

1. SIGNIFICANCE OF HEAT FLOW KINETICS IN BOUNDARY ZONE

Boundary zone structure determines the properties and the durability of composites. Most of the structural parameters also in silumin eutectics is defined in function of temperature gradient and solidification rate [1–18]. Forecasting and optimization of composite matrix structure requires investigation of temperature derivatives after time and direction in particle direct neighbourhood and in other regions. Changes of both derivatives were examined in function of heat flow direction and solidification interval of elementary composite regions. Besides of simplified shape of reinforcing particles applied in simulations the typical industrial composition of composite components was applied. Thermal influences were bond with particles morphology and size by use of following relation:

$$M_m = \frac{S_P}{V_P},$$

where: S_P and V_P are the particle area and volume, respectively.

2. SIMULATION CONDITIONS

Microregion consists of silumin cube which creates the composite matrix. In center of this cube the carborundum particles were placed, with shape of: tetrahedron, cube and a sphere. The three-dimensional heat flow was assumed. Thus, the reinforcing particles are the thermal centers of solidifying castings. The matrix surroundings was the material wit averaged properties of matrix and particles representing the thermophysical properties of modelled composite region containing 10% of SiC reinforcement. Simulation was conducted with use of FEM implemented in Simtec RWP system [19].

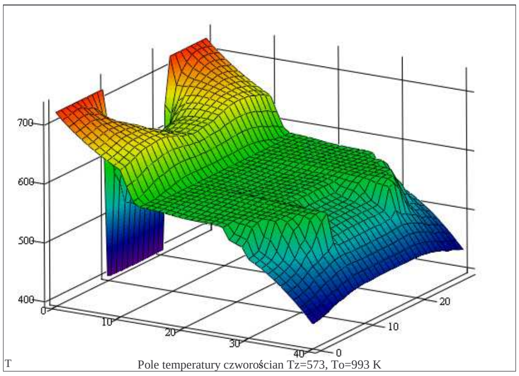
During the geometry modelling procedure the scale of similarity with $k=10^3$ was used and following proportions were used:

- matrix cube edge length 5,28 [cm]
- tetrahedron particle edge length 5,00 [cm]
- cube particle edge length 2,45 [cm]
- sphere particle diameter 3,04 [cm]

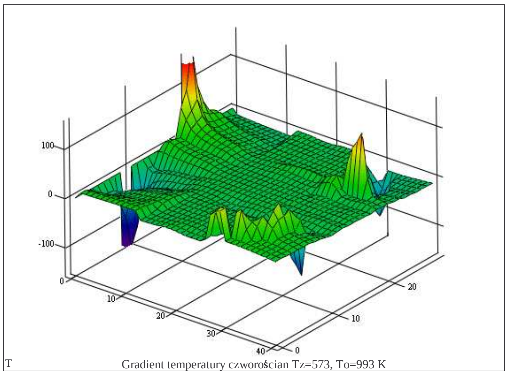
Special modules were assigned to reinforcing particles describing its shape and size. For tetrahedron, cube and the sphere the modules were, respectively: M_{mt}=2,94; M_{mc}=2,45; M_{ms}=1,97 [cm^{-1}]. Initial thermal conditions for reinforcement, matrix, surroundings and the air were as follows: 300, 720, 720, 25 [^{o}C]. Simulation was conducted with use of thermophysical data from the database of the program.

3. STUDIES RESULTS

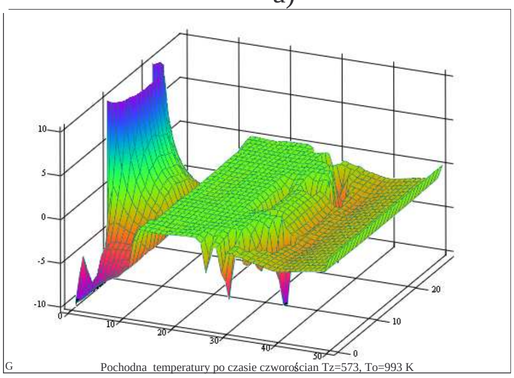
Diagrams on figure 1 show some relations between the temperature, thermal gradient and temperature derivative after time in function of solidification time.



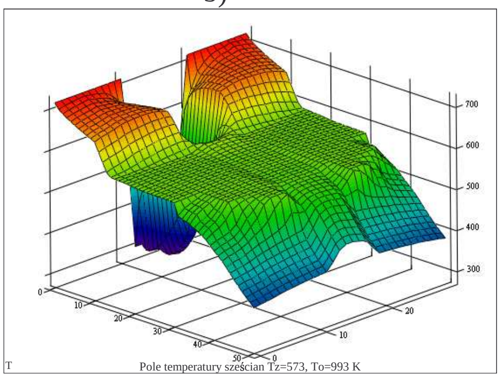
a)



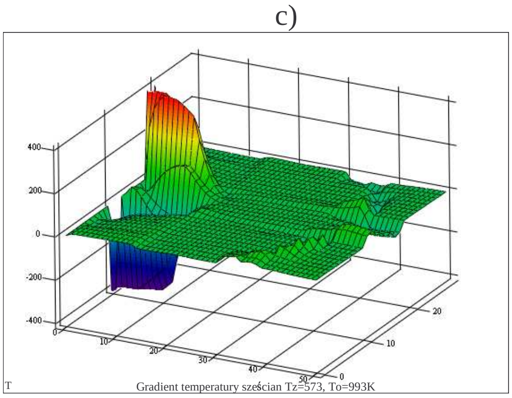
b)



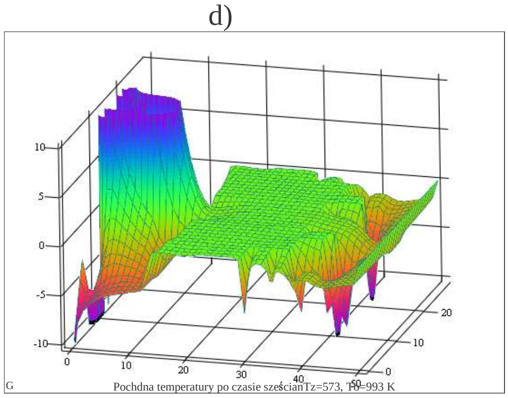
c)



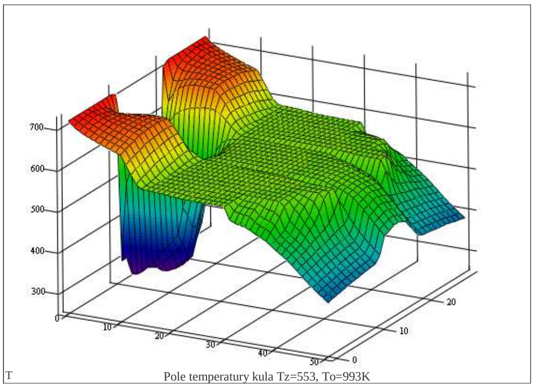
d)



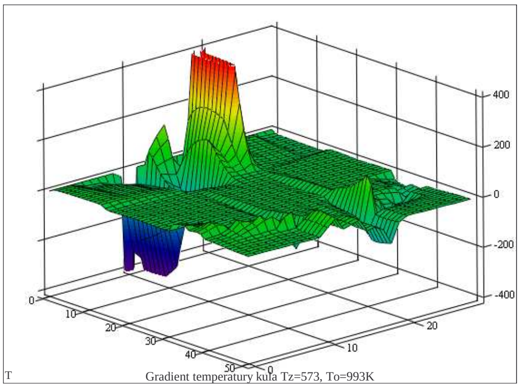
e)



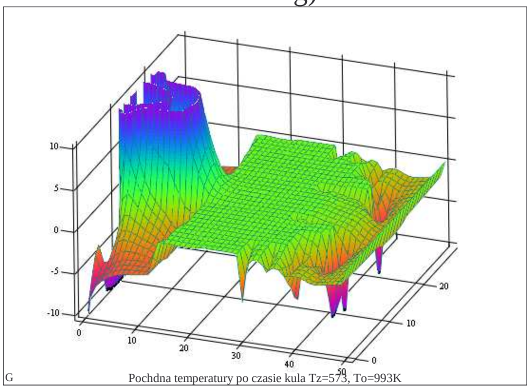
f)



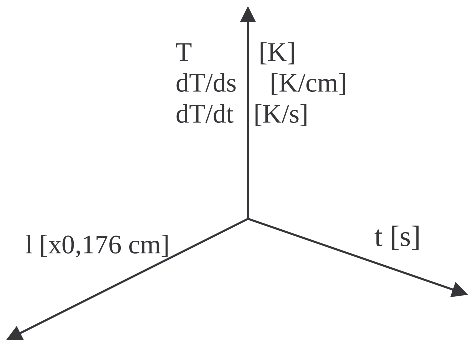
g)



h)



i)



j)

Figure 1. Diagrams of temperature changes and thermal gradient in function of solidification time and heat flow direction. Heat flow direction goes through center of the region containing reinforcing particle: a) – e) tetrahedron particle, f) – i) cube particle, j) – m) sphere particle, m) co – ordinate system. Temperature relations: a), b), f), j) T=f(1, t). Thermal gradient relations: c), d), g), h), k) G=f(1, t). Temperature derivative after time relations: c), i), l) v=(1, t)

Heat axis corresponding with diagram axis starts on one side of conventional matrix and ends on the other side dividing the region on 30 elemetary sections. As a consequence the mirror axial symetry of thermal gradient is obtained.

4. DISCUSSION

In case of particles with compact shape – cube and sphere, thermal gradients in initial period are highest in superficial layers. Its high variability concerns the particle surface. The temperature equalizes at the earliest in microregion with tetrahedron particle. Very important is a reinforcement temperature oscillation near the matrix temperature. Occurance of these changes can be explained by different thermophysical properties of the components and its value diversification by particles morphology. Range just before reaching the solidification interval (specified in figure 1 d and h). It is connected with gradient sign change along the heat flow axis. Gradient initially goes down to 0 value before the particle boundary, on the boundary the gradient sign changes and its value strongly rises showing extreme point near the particle second boundary and just after the second boundry again changes the sign. The gradient sign change is registered on both boundaries of the particle just before reaching the liquidus temperature. Gradient equalization takes place on 0 level. Intensity of changes is the greatest in sphere particle region, then in cube and tetrahedron. The range of changes is the biggest for sphere particle, then cube and tetrahedron. On arbitrary selected ranges proportion of the highest thermal gradients related to gradient in tetrahedron particle region is as follows:

$$i = \frac{G_S}{G_T} = 25{,}6 \qquad i = \frac{G_C}{G_T} = 14{,}7$$

where: G_S, G_T and G_C correspond to gradients of sphere, tetrahedron and cube particles.

5. CONCLUSIONS

1. Assuming constant content of reinforcement with rise of contact surface between components related to reinforcement volume unit – M_m the significant influence of particle shape on temperature distribution and its derivatives after time and direction is observed
2. Region with highest variability of temperature derivatives is boundary zone between the components
3. Locally in particle neighbourhood, in function of direction, before reaching the liquidus temperature gradient changes the sign
4. With decrease in boundary surface area and module M_m rises the thermal gradient in liquid befor reaching the liquidus, the rate of local increases or decreases of temperature also rises
5. Through selection of module M_m and thermophysical parameters values the disperse composites can be created with specific properties for so called suspension casting with internal microchills. An example of such solution can be presented case of carborundum tetrahedron particle in silumin eutectic matrix – created with different initial temperatures.

REFERENCES

1. A. E. Ares, C. E. Schvezov: Solidification Parameters During the CET in Lead – Tin Alloys, Metall. And Mater. Trans.v. 31A, 2000 s. 1611
2. S. Brown, J. A. Spittle, J. D. Janes: The mould Filling and Solidification of a complex Foundry Casting, J.O.M., 2002
3. M. Flemings: Solidification processing, Met. Trans.New York, Mc Graw-Hill Book Co., v. 5, 1974
4. E. Fraś: Krzepnięcie metali i stopów, WN PWN, Warszawa 1992.
5. S. Khan, R. Eliot: Solidification kinetics of the unmodified aluminum – silicon flake structure. Acta Metall. Mater., v. 41, 1993, s. 2433
6. S. Khan, A. Ourdjini, R. Eliot: Interflake spacing – growth velocity relationship in Al-Si and AL-CuAL2 eutectic alloys, Mater. Sci. Technol. v. 8, 1992, s. 516
7. W. Kurz, D. J. Fisher: Fundamentals solidification, Trans, Tech. Publ., Paris 1984.
8. J. Liu, Y. Zhan, B. Shang: Lamellar eutectic stable growth – I. Modeling, Acta Metall. Mater., v. 38, 1990, s. 1625
9. S. Pietrowski: Siluminy, Wyd. Pol. Łódzkiej, Łódź 2001
10. M. Rappaz, C. A. Gandin: Probabilistic Modeling of Microstructure Formation in Solidification Processes, Acta Metall. Mater., v. 41, 1993, s. 345
11. K. Weiss, Ch. Honsel, J. Gundlach: Metoda elementów skończonych w symulacji cieplnej, metalurgicznej oraz mechanicznej Simtec. Przegląd Odlewnictwa 6/1994