AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY,
FACULTY OF FOUNDRY ENGINEERING,
AGH KRAKOW DEPARTMENT OF FOUNDRY PROCESSES ENGINEERING,
REYMONTA 23, 30-059 KRAKOW, POLAND

EXPERIMENTAL VALIDATION OF NUCLEATION AND CRYSTALLIZATION OF Mg-Al ALLOY BASED AZ91/SiC COMPOSITE MODEL

Jakub Graczyk, Sylwia Halek, Paweł Żak, Witold Krajewski, Józef Suchy
kipo@agh.edu.pl

INTRODUCTION

Grain size is one of the most important structural characteristic that determining mechanical properties. Knowing element properties, the proper application regions for it can be chosen to achieve best mechanical properties and performance. Nowadays simulation software can be use to predict the element microstructure. Those programs base on micro-macro model of crystallization. The model consists of partial differential equations (PDEs) that describe the nucleation rate, diffusion in the casting, casting cooling speed and every single grain growth rate. Often it is hard to find the theoretical value of the parameters that appear in those PDEs. It is possible to find them from experiment. The experimental data after applying statistical methods let us find approximated values of the so-called "fitting parameters" in the mentioned models.

EXPERIMENTAL PROCEDURE

The composite with AZ91 metal matrix and SiC reinforcement particles was prepared. Three castings were prepared for different SiC particles size.

Casting conditions			
Casting symbol	A	B	C
Particles size, [μm]	10	40	76
AZ91 mass, [g]	5960	6250	5800
Ambient temperature, [°C]	22	22	24
Furnace temperature, [°C]	750	750	750
Particles temperature, [°C]	320	320	320
In-mould temperature, [°C]	100	100	100
Stirring time, [s]	240	180	180

MODEL ASSUMPTION

Nucleation temperature can be described with the function that depends on mass fraction of the ceramic particles in the composite. During each time step of the simulation there appear specific number of nuclei. In this model there are gather in the structure named class of grains. Each grain in the class have the same radius, and Al concentration at the radius for them is the same. For each time step the volume of representative grain of each class is calculated, than the volume is multiplied by the number of the grains gathered in the class, partial volume values for the grain classes are summarized to obtain total solid volume.

MODEL DESCRIPTION

In the mathematical model it is assumed that heat transfer is governed by Fourier – Kirchhoff (FK) equation:

$$\frac{\partial T}{\partial \tau} = \frac{1}{c_p \rho} div(-\lambda gradT) + \frac{q}{c_p \rho}$$

THE MODIFIED FRAS NUCLEATION MODEL

As an effect of statistical analysis the formula that connects undercooling and reinforcement particles size influence on the volumetric grain density was obtained:

$$N_V(T, d_{SiC}) = 9.1 \cdot 10^{14} \exp\left(3.1 \cdot 10^4 - \frac{32.6 + 1.4 \cdot 10^6 d_{SiC}}{T_N - T}\right)$$

The Al concentration in the grain and in the surrounding liquid determine grain growth speed:

$$(C_L - C_S)\frac{dR}{d\tau} = D_{Al}^{\alpha} \frac{dC}{dr}\Big|_{R^-} - D_{Al}^{L} \frac{dC}{dr}\Big|_{R^+}$$

DIFFUSION SOLID AND LIQUID STATE

$$\begin{cases} \dfrac{dC_\alpha}{d\tau} = D_{Al}^{\alpha}\left(\dfrac{\partial^2 C_\alpha}{\partial r^2} + \dfrac{2}{r}\dfrac{\partial C_\alpha}{\partial r}\right) + \dfrac{r}{R}\dfrac{\partial C_\alpha}{\partial r}\dfrac{dR}{d\tau} \\ C(r=0) = 0.02 \text{ (Al concentrat ion in } \alpha - Mg) \\ C(r \to R^-) = C_S \text{ (phase diagram)} \end{cases}$$

$$\begin{cases} \dfrac{dC_L}{d\tau} = D_{Al}^{L}\left(\dfrac{\partial^2 C_L}{\partial r^2} + \dfrac{2}{r}\dfrac{\partial C_L}{\partial r}\right) + \dfrac{R_0 - r}{R_0 - R}\dfrac{\partial C_L}{\partial r}\dfrac{dR}{d\tau} \\ C(r \to R^+) = C_L \text{ (phase diagram)} \\ C(r = R_0) = 0.09 \text{ (Al concentrat ion in alloy)} \end{cases}$$

SIMULATED AND EXPERIMENTAL COOLING CURVE COMPARISON

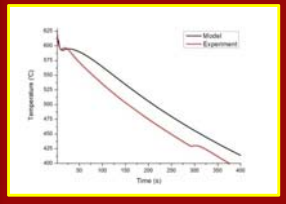

Fig. 1. Cooling curves for 0% SiC

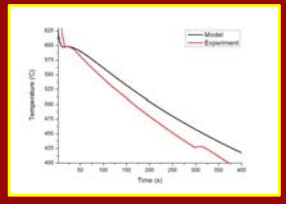

Fig. 2. Cooling curves for 0,1% SiC

Results of the simulation were later validated with experimental casting. The simulation run for composite of 2% content of SiC, d_{SiC} = 45 μm. The results of the simulation are quite similar to the experimental data. Especially at the beginning, for about first 125s of the process the curves are almost identical. Good correlation shows that proposed model is correct.

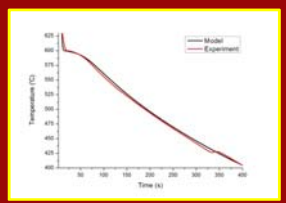

Fig. 3. Cooling curves for 2% SiC

SOLID FRACTION CHANGE VERSUS TIME

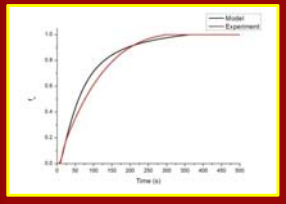

Fig. 4. Solid state fraction for 0% SiC

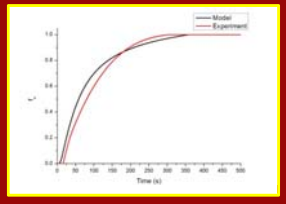

Fig. 5. Solid state fraction for 0,1% SiC

This diagrams shows that the solid fraction grows very fast at the beginning of the crystallization phenomenon and than its speed slows. Alsow the simulation run for all three contents of SiC showed good correlation with experimental data.

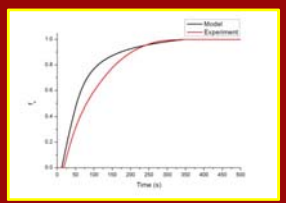

Fig. 6. Solid state fraction for 2% SiC

CONCLUSION

Analysis of experimental cooling curves and the modelled ones shows high accuracy of presented numerical model. The same conclusion can be state when the solid state fraction is taken into account.

Model described above let to take into account nucleation of the magnesium primary phase and its influence on the crystallization of the composite. This feature makes improve accuracy of the numerical solution, that makes possible to predict composite microstructure and properties.