M. SZUCKI, D. KALISZ, J. LELITO, P. L. ŻAK, J. S. SUCHY, K. W. KRAJEWSKI

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MODELLING OF THE CRYSTALLIZATION FRONT – PARTICLES INTERACTIONS IN ZnAl/(SiC)$_p$ COMPOSITES

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The presented work focuses on solid particle interactions with the moving crystallization front during a solidification of the metal matrix composite. The current analyses were made for silicon carbide particles and ZnAl alloy with different additions of aluminium. It was found, that the chemical composition of the metal matrix influences the behaviour of SiC particles. At the same time calculations of the forces acting on a single particle near the crystallization front were performed. For each alloy type the critical conditions that determine whether particle will be absorbed or pushed, were specified.

Key words: modelling, crystallization front, metal matrix composite, SiC particles, reinforcing phase

INTRODUCTION

Metal Matrix Composites (MMC) reinforced by non-metallic particles may be an alternative for widely used light metals alloys. Additions of ceramic particles reinforce the alloy. As the result better values of strength, hardness and abrasion resistance parameters are obtained [1-5].Metal Matrix Composites are widely used especially in the automotive industry for combustion elements and systems that work under high thermal and mechanical stresses [6].

One of the most important factors determining the properties of MMCs is the homogeneous metal matrix structure and the uniform distribution of reinforcement particles. The current analyse was performed on the example of ZnAl/SiC$_p$ ex-situ composite.

It is decided by the number, dimensions and shapes of silicon carbide particles as well as physicochemical effects accompanying the casting process. Several processes related to the interaction of non-metallic particles with the moving crystallization front occur during solidification. In addition, they are accompanied by the effects of floating and agglomeration of SiC particles [7-10]. The clusters formation causes heterogeneity of the material, and in consequence decreasing mechanical properties of the composite [11-14]. Investigations of the distribution process of non-metallic particles were discussed in several papers [10,14-17].

The presented hereby paper deals with the interaction of SiC particles with the crystallization front during casting of two kinds of composites: ZnAl8/(SiC)$_p$ and ZnAl27/(SiC)$_p$ differing in the aluminium content in their metal matrix. The interaction of the single SiC particle with the approaching crystallization front was analysed assuming variable size of the particle moving in the liquid metal matrix.

M. Szucki, D. Kalisz, J. Lelito, P. L. Żak, J. S. Suchy, K. W. Krajewski, AGH University of Science and Technology, Faculty of Foundry Engineering, Kraków, Poland

SINGLE SiC PARTICLE IN THE MOVING CRYSTALLIZATION FRONT

A non-metallic particle being in the vicinity of a vertical crystallization front, which is advancing horizontally, is moving versus the front and surrounding it liquid phase. The particle movement is the result of the force system: gravitational force F_g, resistance of viscous stream F_d and force caused by the local gradient of the fluid velocity S/m s^{-1}, operating in the perpendicular direction towards the front surface, the so-called Saffman force, F_S. The behaviour of the SiC particle is the result of the balance of forces acting on it [17-23]:

Gravitational force, F_g / N

$$F_g = \frac{4}{3} \cdot \pi \cdot r^3 (\rho_m - \rho_p) \cdot g \qquad (1)$$

where: ρ_m – density of ZnAl alloy/kg m^{-3}, ρ_p – density of a particle (reinforcing phase) /kg m^{-3}, g – gravitational acceleration/m s^{-2}, r – radius of a non-metallic particle/m.

The drag force F_d/N – resistance of viscous stream is related to the viscosity of fluid and its value, and in a general case, is regulated by Stokes law. The drag force of a viscous flow taking place in the opposite direction as compared to that of the particle, with the velocity V_p and - in reference to fluid - is presented in the following form:

$$F_d = 6 \cdot \pi \cdot \mu \cdot r \cdot V_p \cdot \theta \qquad (2)$$

where: μ - dynamic viscosity of liquid /kg m^{-1}s^{-1}, Vp - solidification front rate in a steady state /m s^{-1}, h – distance from the front /m.

The value of coefficient θ depends on the flow direction of the particle and its distance from the front h:

θ = 1 for a particle far away from the front, $\theta = \frac{r}{h}$ for a particle approaching the front, and $\theta = \ln\left(\frac{r}{h}\right)$ for a particle moving in parallel to the front.

The Saffman force F_S /N is defined by the following dependence [23]:

$$F_S = 6{,}46 \cdot \mu \cdot r^2 \cdot V_p \cdot \sqrt{\frac{S}{\nu}} \tag{3}$$

where:
ν – kinematic viscosity /m^2 s^{-1}.

The Saffman forces cause approaching or distancing of the particle from the crystallization front.

CALCULATION RESULTS OF FORCES INFLUENCING THE SiC PARTICLE BEING IN THE VICINITY OF THE CRYSTALLIZATION FRONT

On the basis of the above presented equations (1-3) exemplary calculations of the gravity force, drag force and Saffman force for the SiC particle in two kinds of ZnAl/(SiC)$_p$ composites - ZnAl8/(SiC)$_p$ and ZnAl27/(SiC)$_p$, were performed - Figure 1.

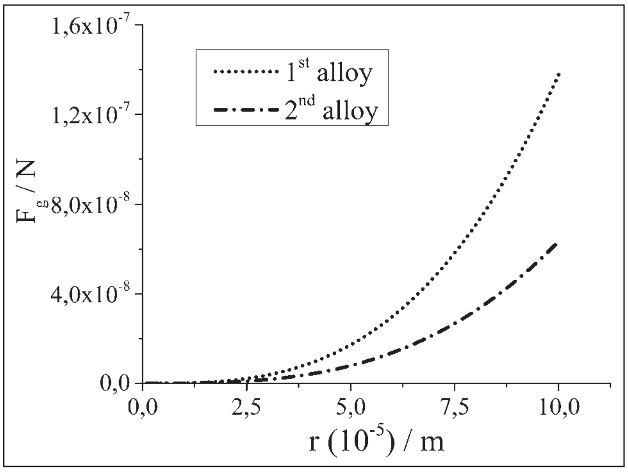

Figure 1 The gravity force F_g against the SiC particle radius. 1st alloy denotes ZnAl8, 2nd alloy ZnAl27

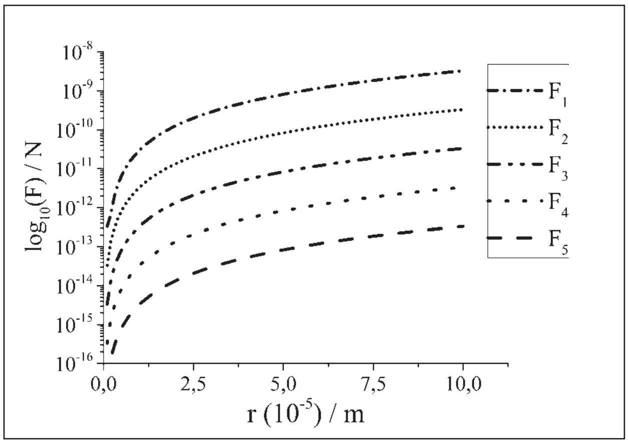

Figure 2 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities V_p= 10^{-6} /m s^{-1} (ZnAl8/SiC$_p$)

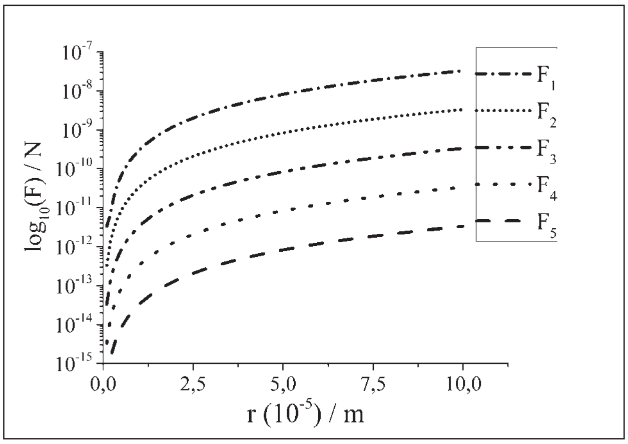

Figure 3 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities V_p= 10^{-5} /m s^{-1} (ZnAl8/SiC$_p$)

The following data were assumed in calculations:

ρ_m – density of an alloy: ZnAl8 - 6 569 /kg m^{-3}; ZnAl27 - 4 754 /kg m^{-3}, ρ_p – density of the SiC particle 3 210 /kg m^{-3}, r – radius of the SiC particle 0,00001 - 0,0001 /m, μ - dynamic viscosity of composites 0,0177 / Pa s^{-1}; ZnAl8/SiC$_p$, 0,0128 /Pa s^{-1} ZnAl27/SiC$_p$, V_p – velocity of the SiC particle in respect to fluid: 0,01 – 0,000001 /m s^{-1}, θ = r/h, h – distance from the front /m, S – local gradient of the fluid velocity 0,000001 – 1 /m s^{-1}.

Computations were performed in order to obtain values of drag force for chosen distances: at Figures 2-7 - F_i denotes force for h_i; where h_1 = 10^{-6}, h_2 = 10^{-5}, h_3 = 10^{-4}, h_4 = 10^{-3}, h_5=10^{-2} /m; and Saffman force for chosen particle velocity: -at Figures 8 and 9 forces F_1, F_2, F_3, F_4, F_5 act on a particle, which moves with the velocity V_p = 0,000001, 0,00001, 0,0001, 0,001, 0,01 /m s^{-1} - respectively.

CONCLUSIONS

Calculations of the gravity force influencing the SiC particle in the vicinity of the crystallisation front indicate that this force influences - to a higher degree - par-

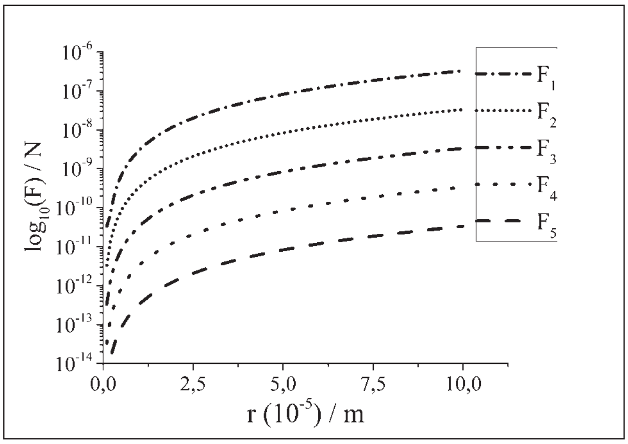

Figure 4 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities Vp= 10^{-4} /m s (ZnAl8/SiC$_p$)

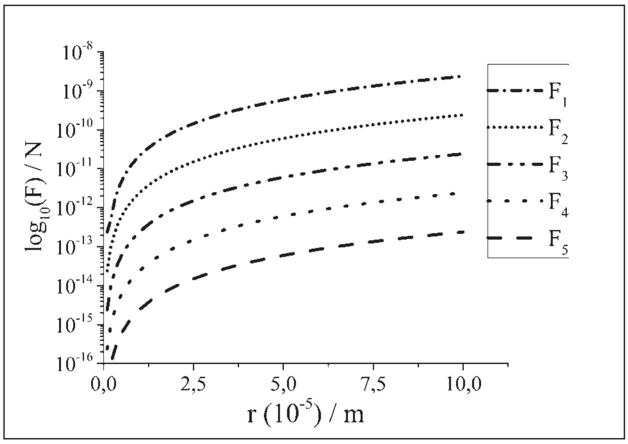

Figure 5 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities $V_p = 10^{-6}$ /m s^{-1} (ZnAl27/SiC$_p$)

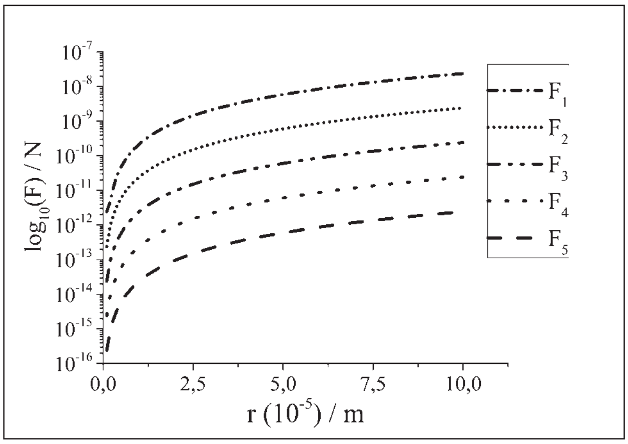

Figure 6 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities $V_p = 10^{-5}$ /m s^{-1} (ZnAl27/SiCp)

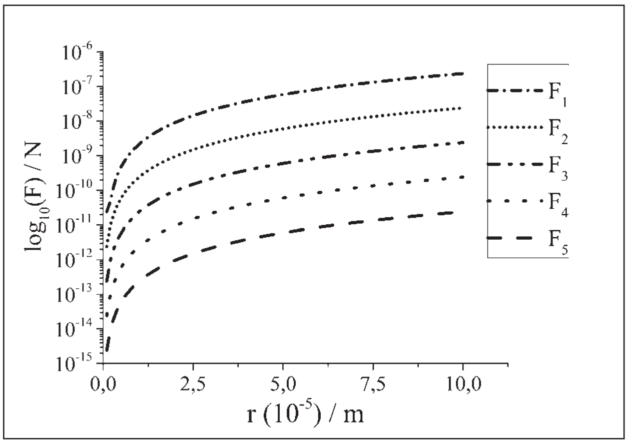

Figure 7 The frictional force F_d for a single SiC particle in the vicinity of a vertical solidification front, which is advancing horizontally, for the particle velocities $V_p = 10^{-4}$ /m s^{-1}, (ZnAl27/SiC$_p$)

ticles of larger sizes and that the matrix density is an essential factor. In case of ZnAl8/(SiC)$_p$ composite the density difference between a particle and matrix equals 3 359 /kg m^{-3}, while for ZnAl27/(SiC)$_p$ composite this difference is more than twice lower (1 544 /kg m^{-3}).

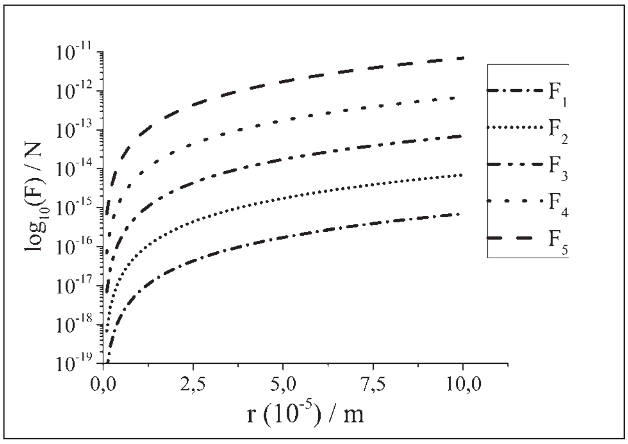

Figure 8 The Saffman forces for ZA8/SiCp composite. (S=0,000001 /m s^{-1})

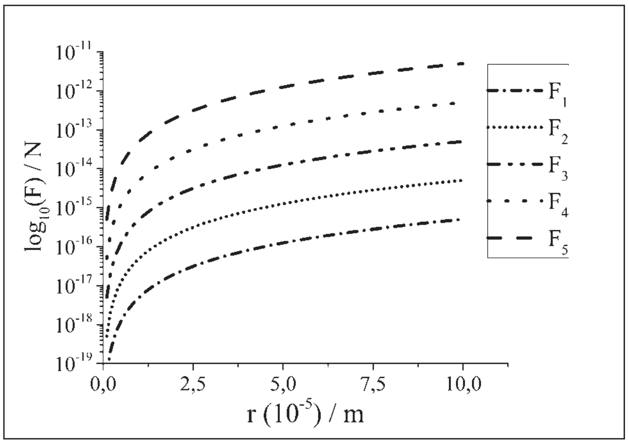

Figure 9 The Saffman forces for ZA27/SiC$_p$ composite (S=0,000001 /m s^{-1})

Consequently, the gravity force is by one order of magnitude lower for ZnAl27 alloy in comparison with ZnAl8 alloy, in case of particles of radiuses of 10^{-4} m. The calculations for very small particles indicated that the matrix density did not influence significantly the gravity force. It was found that the drag force acts in a higher degree on large particles being in the vicinity of the crystallisation front and moving with a higher velocity. It should be stated that the matrix viscosity is the essential parameter, which should be taken into account. During solidification as a temperature decreases, which increases the viscosity. Also an increased amount of the SiC particles added to the composite will influence the viscosity increase. That is why the real value of the flow resisting force, resulting from local conditions, will be higher than the calculated one.

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