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Multiphase Simulation of Aluminum A356 Metal Foam Formation Process by Lattice Boltzmann Method

H. Bayani, M. H. Mirbagheri*

Department of Mining and Metallurgy Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: In this study simulation of a two phase bubble nucleation and growth in aluminum A356 in form grip metal foam process was investigated by two steps. At first for modifying current shanchem methos two inline bubble interaction is studied and then two inline bubble integration detail was investigated. Finaly more than two bubble interaction and integration in molten metal environment studied. Results show an interesting difference in bubbles interactions in molten metal compared two other environments. For this purpose at first, for bubble dynamics in molten metals modeling shan-chen model is used. After discretization of problem equation and all alghorithms impelementation, lattice Boltzmann method was used to numerically solve process discrited equations in all domain. By using the developed code in this research cellular structure of metal foam after solidification is predicted in different temperature. Simulated porous structures were compared with metallographic samples of foamed A356 aluminum at 675, 725 and 775 . The results visualy are very similar to actual samples and also the compesion between virtual and actual samples shows best fit in distribution and mean bubbles size between simulation results of current code and metallographic results of actual sample at 675 . Therefore, the current code could be a useful tool for prediction of aluminum foams cellular structure.

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1- Introduction

Metal foams as a complex of solid bubbles are known for their unique physical and mechanical properties [1, 2]. It is generally accepted that formability of metal foams is intimately correlated with the presence of particles. The physical understanding of foam formation in the presence of colloidal particles with no surface active material is very complex and still rather poor [3]. A variety of studies has been done to analyze the bubble stabilization parameters, most of which are focused on ionic liquids, especially in water. In addition, due to the presence of metallic bond in metal melt, no ionic or polar attraction/repulsion force is present, causing a different behavior of the liquid-gas interface in molten-metal in comparison with aqueous solutions. Different approaches are available for bubbling simulation with their own advantages and disadvantages [4]. Lattice Boltzmann Method (LBM) is the most accurate numerical method. It models the microscopic and mesoscopic kinetic equations and requires no equation or correlation to include source terms in governing equations. Also interface is a post-processed quantity and not a mathematical boundary [5, 6]. Bermond et al [7] performed computational investigation on bubble interactions. Some researchers [8,9] used LBM to simulate fluid flow to determine bubble coalescence conditions.

In this study we propose a new model based on Shan-Chen scheme [10,11] for prediction of bubbles' merging phenomena in Al-Si liquid foams without kiss-point rupturing. Simulation results were validated through conducting experimental work.

2- Methodology

When foaming starts, bubbles are very small (nuclei bubbles<5 microns) and are abruptly produced by dissolution reaction of blowing agent around the melt (micro-scale). Then growth (meso-scale, above 100 microns) starts and bubbles' equilibrium throughout the melt is a function of various underlying forces. Bubble growth, coalescence by cell wall rupture, drainage, and finally foam collapse are the four main stages of the process (macro-scale). Fluid dynamics, interfacial and capillary forces are factors behind the scene [3]. There are two phases in a foam melt system: gas and liquid. Interaction of these two phases forms the final structure of the foam. Interactions on phase boundaries and choice of boundary conditions is deterministic. By using a random function, bubble growth starts after nucleation. To model the growth phenomena in each time step, gas is added by virtual blowing agent to each bubble, giving rise to bubble volume due to pressure balance. Gas blowing (growth) continues until blowing agent is finished. Other phenomena like drainage and wall rupture are considered in growth process by equilibrium bubble equations. Wall rupture and merging phenomenon need additional criterion which could be either an experimental one or a mathematical condition [11].

2- 1- Numerical model

A time random model is developed to determine nucleation site positions. Decomposition of the blowing agents is accordingly calculated for these positions. Other lattice points are filled with a liquid with A356 alloy density. All parameters are changed to dimensionless properties by OpenLB code. Shan-Chen model is based on incorporating long-range attractive forces (F) between distribution functions. Based on classical mechanics theory, the potential force is defined as $p_0 = \rho c_s^2 + 0.166 G\psi^2$ in which ρ, c_s, and G are density, speed

Corresponding author, E-mail: smhmirbagheri@aut.ac.ir

of sound, and strength of the attraction respectively. This equation can describe the separation of phases by choosing suitable pseudo-potential function $\psi(x)$. In the case of Al-Si alloy liquid and the hydrogen gas, the density ratio is large. Hence, we chose the pseudo-potential as $\psi(\rho) = 1 - \exp(-\rho)$. This allows separation of gas and liquid in larger density ratios [12].

Present model is a modification of Shan-Chen model in which, each phase is considered in a separate lattice (grid), i.e. two separate simulations are carried out simultaneously for a two-phase model.

2- 2- Experimental model

Aluminum A356 alloy was melted with electric furnace with ±5ºC tolerance at 700°C. Next, 1.5%wt TiH_2 was added to melt and mixing for a few minutes in the crucible. The mixture containing bubbles' nuclei was cast in a pre-heated steel mold and transferred to a furnace. Finally, the mold was quenched in water and solidified. The solid foam was cut for metallography testes. Morphology, distribution and number of solid bubbles (PPI), and number of merged bubbles were studied under optical microscope. Results were compared with virtual images from modeling tries.

3- Results and Discussion

Both the LB method by unmodified Shan-Chen model in OpenLB and Finite Element Method (FEM) with level set model in COMSOL software yield to the same result. However, this behavior is not acceptable for molten metals foaming process since there is no kiss-point at the intersection of two bubbles. Therefore, none of the existing methods works well. The modified Shan-Chen method developed here is expected to simulate the situation more accurately.

Fig.1 indicates that a film is formed at the interface. No merging occurs until a specific criterion is met. This confirms the capability of the proposed model in simulating real conditions.

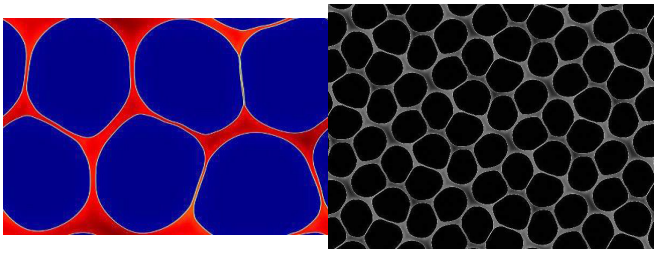

Figure 1. Bubbles cell walls thinning simulation during growth step for small foam domain

Bubbles start to interact when they reach each other and simulation continues until the first cell ruptures. Continued simulation is accompanied by merging and coalescence, leading to drainage in metal foam structure.

In Fig. 2, simulation results are compared with real A356 foam samples. The accuracy of the simulation (evaluated by PPI, bubble area and morphology, and number of merging defects) is above 95%. Therefore the present code can simulate and predict bubble structure of A356 alloy before merging, drainage, and aging of liquid foam.

4- Conclusions

A new model based on Shan-Chen model was proposed in this work for simulation of metal foams at micro and meso scale during foaming stage. In contrast to the existing models, the new model is capable of simulation multi-bubbles with no limitation of number of bubbles. An accuracy better than 95% was confirmed when comparing simulation results with experimental observations in A356 alloy. The model can consider effect of the attraction-repulsion barriers between bubbles due to the impurity. Therefore developed code can be used for controlling and prediction of foam optimum density.

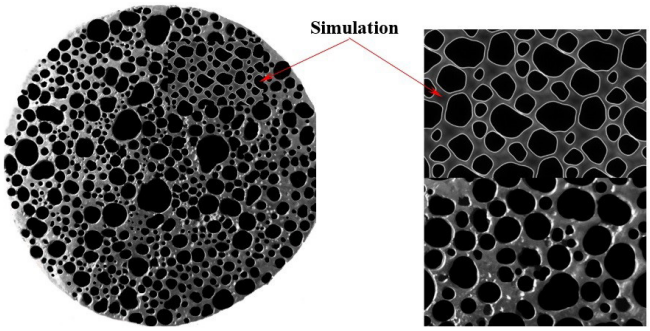

Figure 2. Comparison between the real and the simulated structure of porous A356 Al foam by adding present code

References

[1] J. Banhart, Manufacture, characterisation and application of cellular metals and metal foams, *Progress in Materials Science*, 46(6) (2001) 559-632.

[2] C. Körner, *Integral Foam Molding of Light Metals*, Springer, 2008.

[3] C. Körner, Foam formation mechanisms in particle suspensions applied to metal foams, *Materials Science and Engineering: A*, 495(1) (2008) 227-235.

[4] D.P. Playne, K.A. Hawick, M.G.B. Johnson, Simulating and benchmarking the shallow-water fluid dynamical equations on multiple graphical processing units, in: *Proceedings of the Twelfth Australasian Symposium on Parallel and Distributed Computing* - Volume 152, Australian Computer Society, Inc., Auckland, New Zealand, 2014, pp. 29-36.

[5] A. Gupta, R. Kumar, *Lattice Boltzmann Simulation to Study Multiple Bubble Dynamics*, (43025) (2007) 1593-1604.

[6] S. Ghosh, A.K. Das, A.A. Vaidya, S.C. Mishra, P.K. Das, Numerical Study of Dynamics of Bubbles Using Lattice Boltzmann Method, *Industrial & Engineering Chemistry Research*, 51(18) (2012) 6364-6376.

[7] N. Bremond, M. Arora, S.M. Dammer, D. Lohse, Interaction of cavitation bubbles on a wall, *Physics of Fluids*, 18(12) (2006) 121505.

[8] D. Anderl, M. Bauer, C. Rauh, U. Rude, A. Delgado, Numerical simulation of adsorption and bubble interaction in protein foams using a lattice Boltzmann method, *Food Funct*, 5(4) (2014) 755-763.

[9] C. Körner, T. Pohl, U. Rüde, N. Thürey, T. Zeiser, *Parallel Lattice Boltzmann Methods for CFD Applications*, in: A.M. Bruaset, A. Tveito (Eds.) Numerical Solution of Partial Differential Equations on Parallel Computers, Springer Berlin Heidelberg, Berlin, Heidelberg, 2006, pp. 439-466.

[10] X. Shan, H. Chen, Lattice Boltzmann model for simulating flows with multiple phases and components, *Physical Review E*, 47(3) (1993) 1815-1819.

[11] H. Stanzick, M. Wichmann, J. Weise, L. Helfen, T. Baumbach, J. Banhart, Process Control in Aluminum Foam Production Using Real-Time X-ray Radioscopy, *Advanced Engineering Materials*, 4(10) (2002) 814-823.

[12] A. Kuzmin, J. Derksen, *Shan-chen multiphase model*, in, University of Alberta, 2011.

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