Simulation of Thermal and Solidification Evolution of Molten Aluminum Alloy and SiC Nanoparticles for Engineering Practices

N. K. Kund, S. Patra

Abstract*: *2D numerical model is developed for semisolid casting of A356 alloy mixed with SiC nanoparticles. Throughout solidification the temperature falls from core to the surface. It may be attributed to comparatively higher cooling rate at surface than that of at core. Furthermore, the presence of temperature gradient between surface and core is only on account of finite thermal conductivity between the same. Additionally, the existence of specified temperature gradient may be because of finite handling time. In general, the existence of specified finite temperature gradient is definitely owing to Fourier heat transfer concerning infinite heat or thermal wave speed and frequency. In other words, the temperature gradient falls with rise in cooling/solidification time. However, the nature of simulation forecasts are unquestionably similar. Moreover, the variation of optimum temperature with cooling/solidification time is witnessed to be nearly linear. Furthermore, when quenched for 30, 60, 90 and 120 s, simulation forecasts of maximum flow region temperatures of the said semisolid cast part are 500, 450, 400 and 350 K, respectively.

Index Terms*: *Numerical, Semisolid cast part, A356 alloy, SiC nanoparticles.

I. INTRODUCTION

Semisolid processing of A356 alloy without mixing with any type of nanoparticle are thoughtfully ruminated in literatures [1-2]. Comparable modeling and simulation practices are perceptible profligately in literatures [3-18]. The mentioned texts unveil no comprehensive numerical investigation on semisolid cast part. Thus, present article crafts deep numerical valuations of semisolid cast part.

Additionally, numerical model determines first-hand officious matters like stillness, stickiness and gravitational factors beneath collective concerns of present industrial problem. Nevertheless, reckoned modeling defies compressibility and glutinous decadence impacts. Numerical model is framed for comprehensive thermal studies on semisolid cast part. Lastly, current simulation results are alongside expected lines.

II. PHYSICAL PROBLEM DEFINITION

Quite unambiguous representation of 2D semisolid cast part is presented in fig. 1. Associated 2D computational domain of semisolid cast part is developed in fig. 2. Thermo-physical things of nanoparticle and system essentials are acknowledged in table 1. Modeling entangles viscosity and gravity. No slip laminar and incompressible melt flow situation prevails. Melt inlet velocity is experienced at entry. Even though, convection is practiced at boundary.

III. MATHEMATICAL FORMULATIONS

2D continuity, momentum and energy equations of current production problem are precisely clear in equations (1), (2) and (3), one-to-one.

Continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

X-momentum:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (2a)$$

Y-momentum:

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g \qquad (2b)$$

Energy:

$$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \qquad (3)$$

IV. NUMERICAL METHODS

Every single equation is discretized with upwind scheme and pressure based FVM using SIMPLER algorithm. GI trial unravels moderate number of grids with time step 10^{-4} s. Convergence is confirmed when $\left|\frac{\varphi-\varphi_{old}}{\varphi_{max}}\right|\leq 10^{-4}$ is realized for each variable, where φ is any flow parameter out of u, v, p and T.

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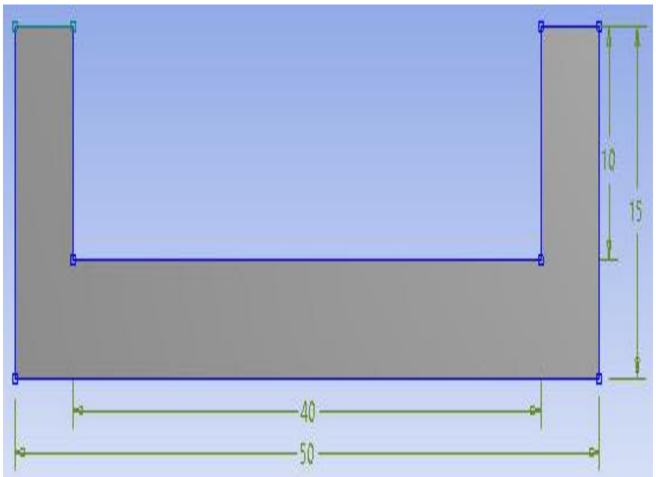

Fig. 1: 2D model of semisolid cast part

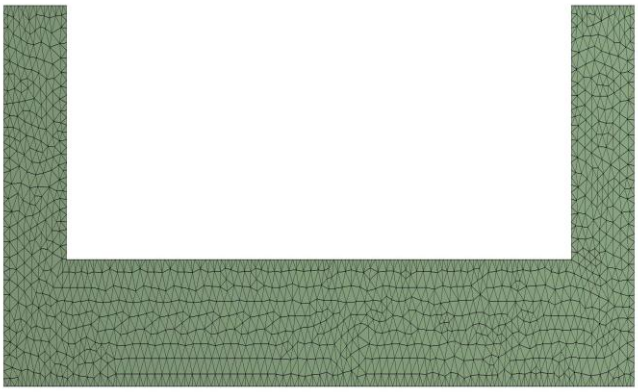

Fig. 2: 2D computational domain of semisolid cast part

Table 1. Thermophysical properties of nanoparticle and model data

Nanoparticle Properties	**SiC**
Density, ρ (Kg/m^3)	3200
Specific heat, C_P (J.Kg^{-1}.K^{-1})	680
Thermal conductivity, k (W/m-K)	500
Model Data	**Values**
H	15 mm
h	10 mm
W	50 mm
w	40 mm
Water coolant temperature	300 K
Melt velocity	8 m/s

V. RESULTS AND DISCUSSIONS

Figure 3 renders computationally forecast colored temperature field cohesive with vertical scale bar of semisolid cast part of A356 alloy mixed with SiC nanoparticles when quenched at 30 s. As projected the temperature drops from core to the surface that varies from 500 K to 300 K. It may be attributed to relatively higher cooling rate at surface directly exposed to external water coolant as compared that of at core not at all exposed to outer water coolant. In addition, the existence of temperature gradient between surface and core is only because of finite thermal conductivity between the same. Furthermore, the presence of stated temperature gradient may be attributable to finite processing time. In general, the occurrence of stated finite temperature gradient is certainly caused by Fourier heat transfer involving infinite heat/thermal wave speed and frequency.

Additionally, figures 4-6 demonstrate numerical predictions of temperature fields of the stated semisolid cast part of A356 alloy with SiC nanoparticles when quenchied at 60, 90 and 120 s, respectively. Correspondingly, the maximum flow field temperatures are 450, 400 and 350 K, respectively. In other words, the temperature gradient decreases with increase in cooling or solidification time. However, the trends of numerical predictions are certainly similar. Furthermore, figure 7 also summarizes the variation of optimum temperature with cooling or solidification time which is witnessed to be nearly linear.

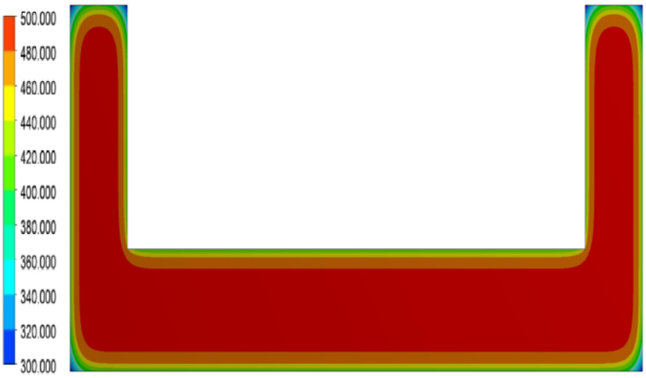

Fig. 3: Temperature field of semisolid cast part after quenching for 30 s

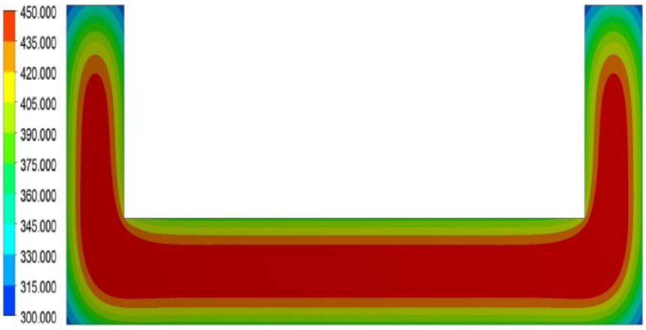

Fig. 4: Temperature field of semisolid cast part after quenching for 60 s

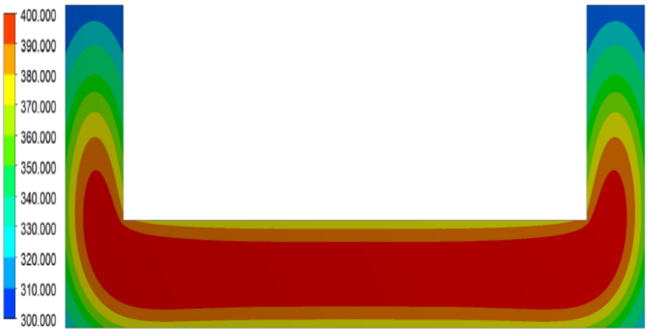

Fig. 5: Temperature field of semisolid cast part after quenching for 90 s

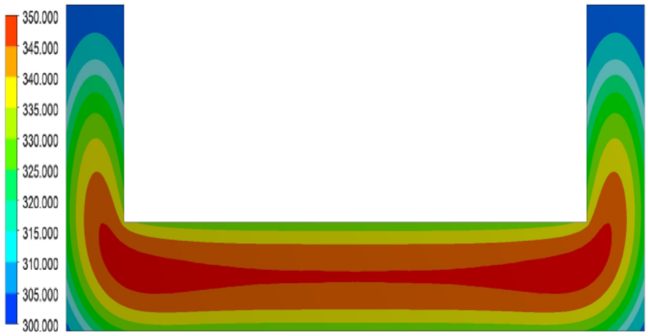

Fig. 6: Temperature field of semisolid cast part after quenching for 120 s

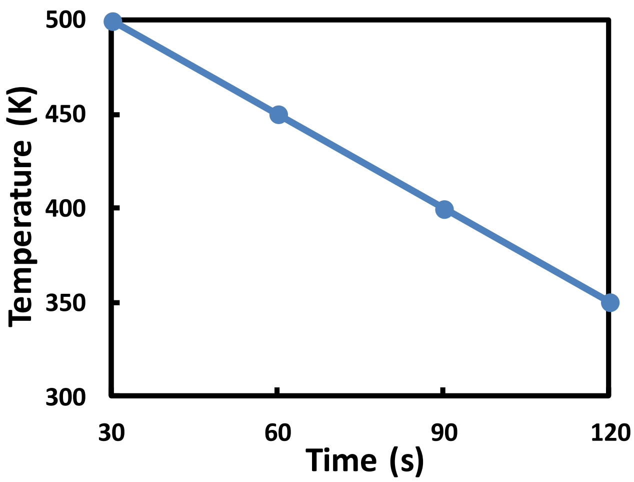

Fig. 7: Variation of optimum temperature with time

VI. CONCLUSION

2D simulation model is established for semisolid casting of A356 alloy mixed with SiC nanoparticles. Throughout solidification the temperature drops from core to the surface. It may be attributed to reasonably higher cooling rate at surface rather than at core. Furthermore, the presence of temperature gradient between surface and core is only due to finite thermal conductivity between the same. Moreover, the occurrence of specified temperature gradient may be owing to finite handling time. Generally, the existence of specified finite temperature gradient is indeed resulting from Fourier heat transfer concerning infinite heat/thermal wave speed and frequency. In other words, the temperature gradient drops with rise in cooling/solidification time. But, the developments of simulation results are definitely similar. Besides, the variation of optimum temperature with cooling/solidification time is detected to be nearly linear. Additionally, simulation results of maximum flow region temperatures of the specified semisolid cast part are 500, 450, 400 and 350 K when quenched at 30, 60, 90 and 120 s, one-to-one.

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