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CFD Studies on Heat Transfer and Solidification Progress of A356 Al Alloy Matrix and Al_2O_3 Nanoparticles Melt for Engineering Usages

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Abstract*: 2D model is established for semisolid forming of SSF component of A356 Al alloy mixed with Al_2O_3 nanoparticles. During solidification the temperature decreases from core to the surface. It may be credited to relatively higher cooling rate at surface as compared that of at core. Moreover, the existence of temperature gradient between surface and core is only because of finite thermal conductivity between the same. In addition, the presence of stated temperature gradient may be attributable to finite processing time. At large, the occurrence of stated finite temperature gradient is certainly caused by Fourier heat transfer involving infinite heat or thermal wave speed and frequency. In other words, the temperature gradient decreases with increase in cooling or solidification time. Nevertheless, the trends of numerical predictions are certainly similar. Furthermore, the variation of optimum temperature with cooling or solidification time is observed to be almost linear. Additionally, after quenching for about 30, 60, 90 and 120 s, numerical predictions of maximum flow field temperatures of the stated SSF component are 500, 450, 400 and 350 K, respectively.

***Index Terms*: Numerical, SSF component, A356 Al alloy, Semisolid forming, Al_2O_3 nanoparticles.**

I. INTRODUCTION

SSM processing of A356 Al alloy without mixing with any kind of nanoparticle are gallantly mused in texts [1-2]. Similar modeling and simulation studies are noticeable extravagantly in texts [3-18]. The quoted manuscripts disclose no all-embracing numerical research on SSF component. Consequently, current article crafts deep numerical assessments of SSF component.

Furthermore, mathematical model clinches new domineering subjects such as stillness, stickiness and gravitational terms beneath collective concerns of present industrial problem. All the same, reckoned modeling defies compressibility and glutinous decadence impacts. Mathematical model is framed for far-reaching thermal studies on semisolid forming of SSF component. Finally, present model predictions are along anticipatable lines.

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II. DESCRIPTION OF PHYSICAL PROBLEM

Very clear-cut picture of 2D SSF component is showed in fig. 1. Corresponding 2D computational domain of SSF component is established in fig. 2. Thermo-physical chattels of nanoparticle and system elements are declared in table 1. Modeling ensnares viscosity and gravity. No slip laminar and incompressible melt flow. Melt inlet velocity is practiced at entrance. Despite, convection is experienced at boundary.

III. NUMERICAL FORMULATION

2D continuity, momentum and energy equations of present engineering problem are very well-defined in equations (1), (2) and (3), respectively.

Continuity:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

X-momentum:

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

Y-momentum:

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

Energy:

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

IV. NUMERICAL PROCEDURES

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

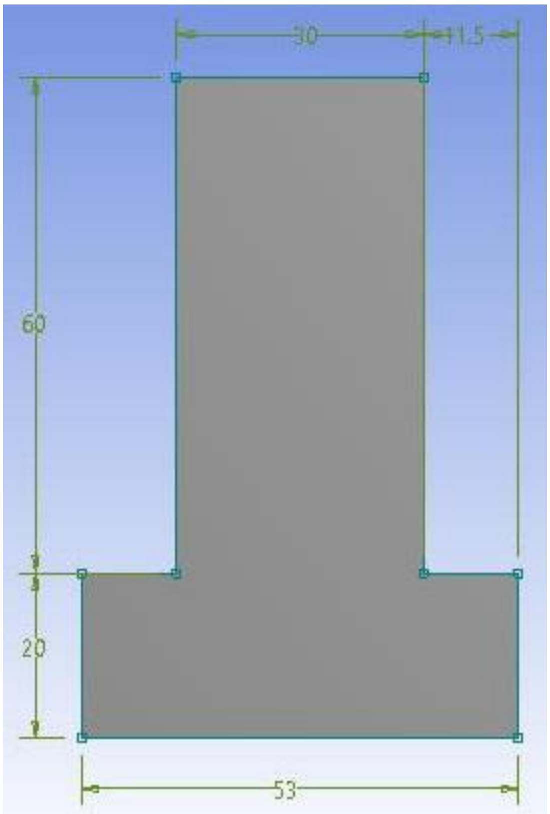

Fig. 1: 2D model of SSF part

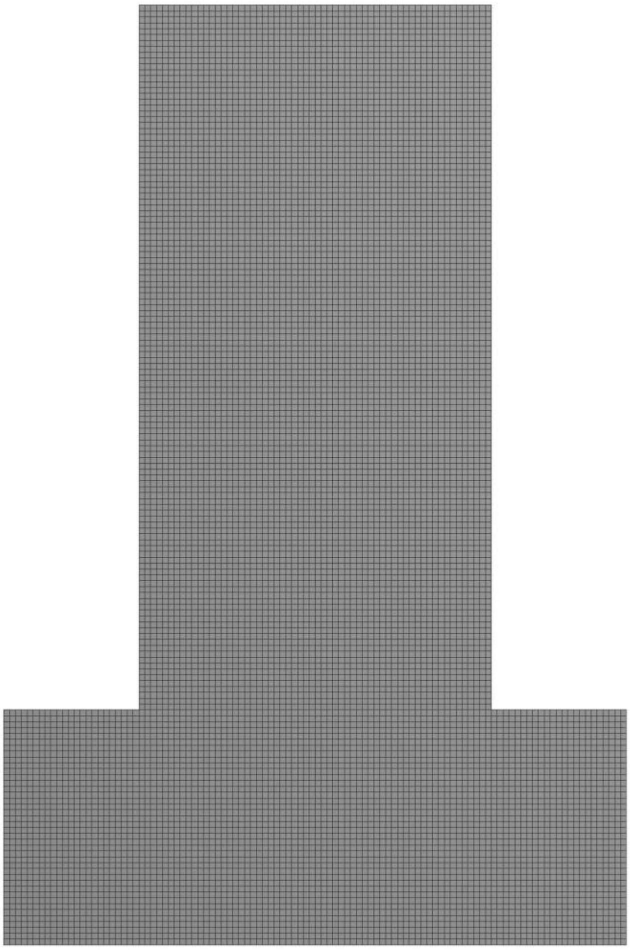

Fig. 2: 2D computational domain of SSF part

Table 1. Thermophysical properties of nanoparticle and model data

Nanoparticle Properties	**Al_2O_3**
Density, ρ (Kg/m^3)	4000
Specific heat, C_P (J.Kg^{-1}.K^{-1})	770
Thermal conductivity, k (W/m-K)	40
Model Data	**Values**
W	53 mm
H	60 mm
w	30 mm
h	20 mm
Water coolant temperature	300 K
Melt velocity	8 m/s

V. RESULTS AND DISCUSSIONS

Figure 3 portrays (numerically predicted) colored temperature field integrated with vertical scale bar of SSF component (of A356 Al alloy mixed with Al_2O_3 nanoparticles) after quenching for about 30 s. As expected the temperature decreases from core to the surface which ranges between 500 K and 300 K. It may be credited to relatively higher cooling rate at surface (which is directly exposed to external water coolant) as compared that of at core (actually 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.

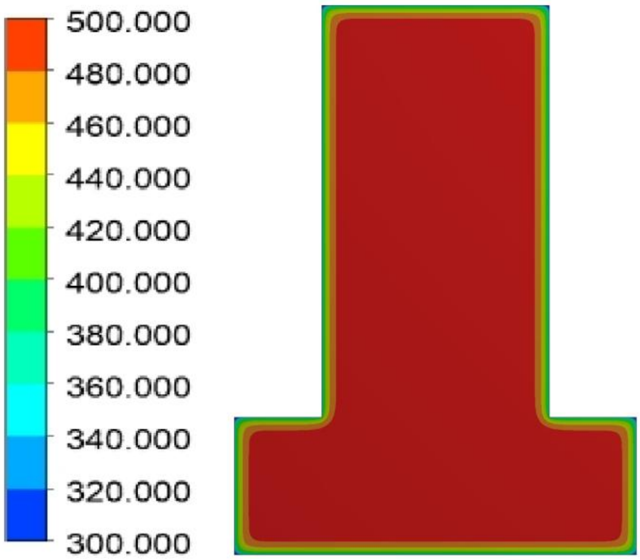

Fig. 3: Temperature field of SSF component after quenching for 30 s

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Furthermore, figures 4-6 demonstrate numerical predictions of temperature fields of the stated SSF component (of A356 alloy with Al_2O_3 nanoparticles) after quenching for about 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/solidification time. However, the trends of numerical predictions are certainly similar. In addition, figure 7 also summarizes the variation of optimum temperature with cooling/solidification time which is observed to be almost linear.

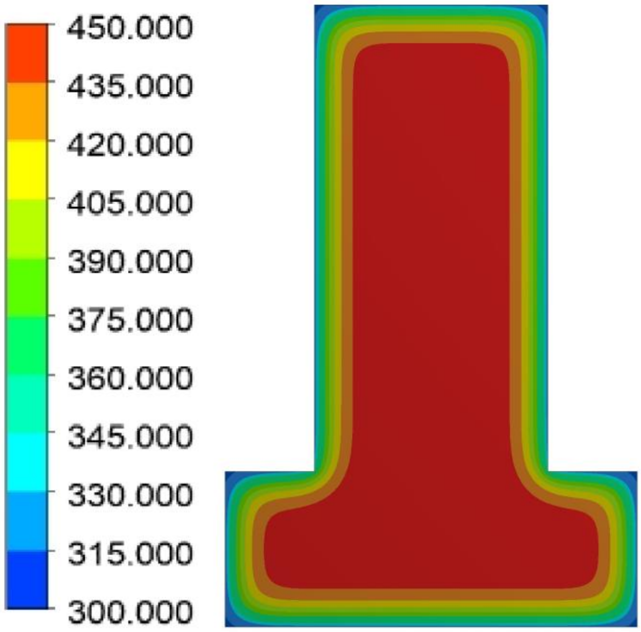

Fig. 4: Temperature field of SSF component after quenching for 60 s

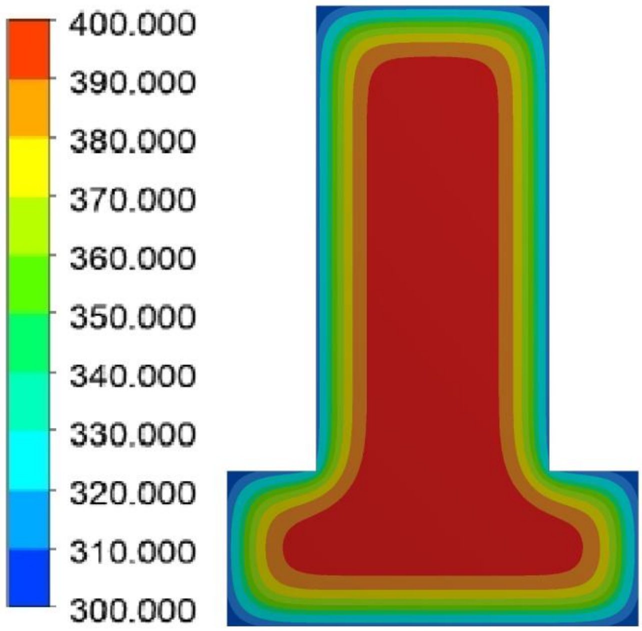

Fig. 5: Temperature field of SSF component after quenching for 90 s

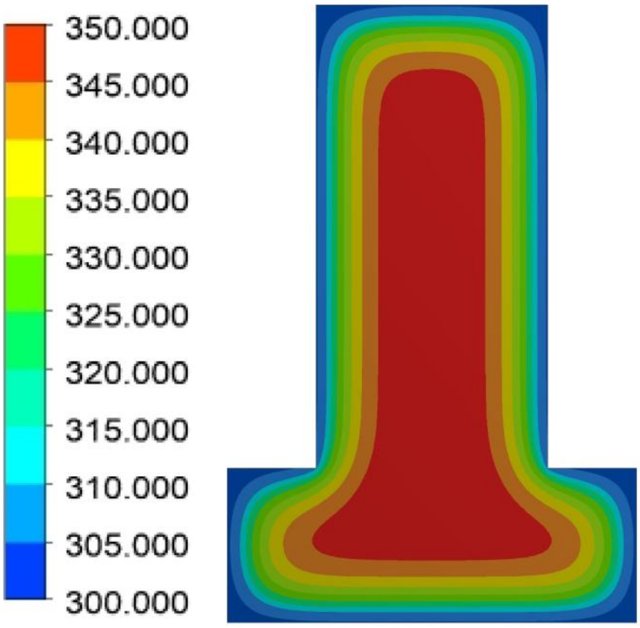

Fig. 6: Temperature field of SSF component after quenching for 120 s

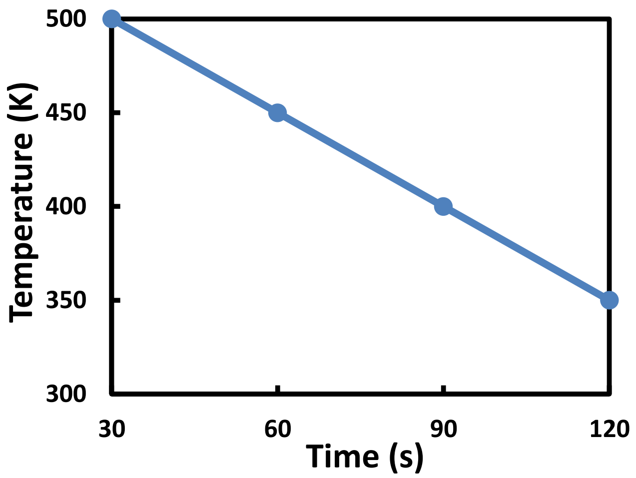

Fig. 7: Variation of optimum temperature with time

VI. CONCLUSION

2D numerical model is developed for semisolid forming of SSF component of A356 Al alloy mixed with Al_2O_3 nanoparticles. During solidification the temperature decreases from core to the surface. It may be credited to relatively higher cooling rate at surface as compared that of at core. 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 or thermal wave speed and frequency.

In other words, the temperature gradient decreases with increase in cooling or solidification time. However, the trends of numerical predictions are certainly similar. In addition, the variation of optimum temperature with cooling or solidification time is observed to be almost linear. Furthermore, numerical predictions of maximum flow field temperatures of the stated SSF component are 500, 450, 400 and 350 K after quenching for about 30, 60, 90 and 120 s, respectively.

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