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SOLIDIFICATION SIMULATION OF Al 6061 CASTING IN 2-D GREEN SAND MOULD

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ABSTRACT: *Numerical simulation of Al 6061 in green sand mould has been studied. Two-dimensional heat conduction equation governs the physical problem. Convective condition has been considered at the interfaces where molten metal meets the mould cavity surface. Finite difference technique has been adopted to solve the heat conduction equation in unsteady state and transient state.Central difference scheme for spatial terms and explicit scheme for temporal term have been adopted to discretize the governing equation. MATLAB package has been used to study the thermal flow and cooling rate. Green sand as mould cavity material and Al 6061 as molten metal material has been considered. Temperature distribution of Al 6061in green sand mould for two-dimensional casting for steady problem and cooling rate of with time have been plotted.*

Keywords:*Numerical simulation, Conduction heat transfer, Al 6061 and green sand mould*

Nomenclature

L	Length of the Cavity (x-direction)	h_f	Latent heat of fusion
H	Height of the Cavity (y-direction)	A	Thermal Diffusivity
T	Temperature	P	Density
t	Time	C_p	Specific heat
k	Thermal Conductivity	∞	Reference Value

I. INTRODUCTION

Casting which also referred as founding is one of the soonest metal shaping methods known to human being. It normally means the pouring of liquid metal into the refractory mould with an enclosure of the shape to be made then permitting it to solidify. When solidified, the desired metal object is taken out from the refractory mould either by breaking the mould or ejecting the mould part. The solidified part is called casting. Casting has been extensively used in manufacturing because of its many applications and advantages.

Mould Cavity Employed

As types of mould employed for casting is strongly influences the quality of the cast part in terms of dimensions, shape, surface finish and internal quality of the casting part; hence, it is indispensable the appropriate selection and control of the materials of which the mould is made. AI 50/60 AFS mould (green sand mould with industrial sand) has been employed in present work.

Mathematical Formulation

Physical Domain

Fig. 1 shows the schematic of system, one can notice that solid red lines represent the boundaries of the casting part where the solidification of the Al 6061will takes place. Outer and inner part is made of green sand.Molten metal poured in the mould cavity from opening at the top of the cavity. Thick line which represents the walls of the casting at which heat transferred by conduction is equal to the heat transferred by convection, finally heat is transferred to the atmosphere.

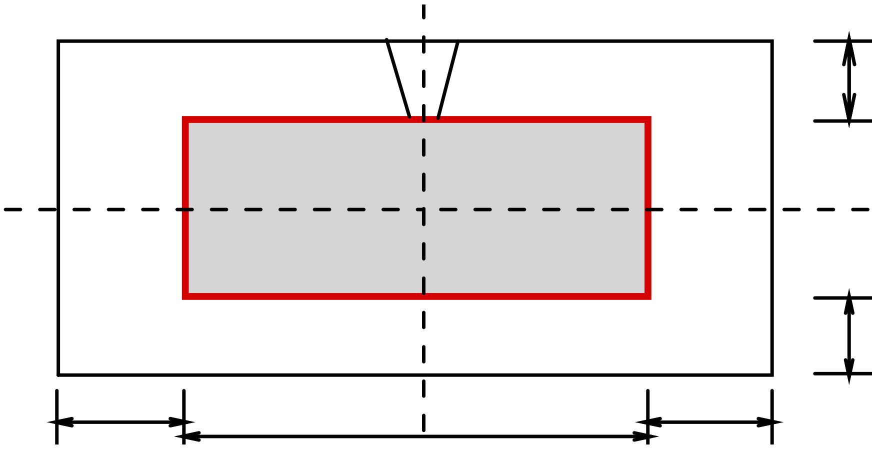

Figure 1. Schematic of mould cavity

Governing Equation

$$\rho C_p \frac{\partial T}{\partial t} + \left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \quad (1)$$

$$\rho C_p \frac{\partial T}{\partial t} + \left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad (2)$$

Above equations 1 and 2 are two-dimensional Energy equations in unsteady form with temperature dependent and temperature independent thermal conductivity respectively. First term on the left hand side of the equation characterizes the variation of the temperature with the time which represents the unsteady heat transfer and second term is convective part which comes into play due to movement of the molecules, while term on right hand side characterizes the variation in the spatial direction which represents the diffusive part. Other two modes of heat transfer, convection and radiation has been neglected inside the fin, because present study is focusing on designing of a solid-fin and it is well known fact that inside the solid body heat transfer by conduction dominate over convection and radiation. So the above equation will reduces to a simple form by neglecting the second term on the left hand side,

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \quad (3)$$

$$\rho C_p \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

Where: $\alpha = k/\rho C_p$ is thermal diffusivity in m^2/s, k is thermal conductivity in W/m-K, ρ is density in Kg/m^3, C_p is specific heat J/Kg-K, T is temperature in Kelvin (K), t is time in seconds.

The above equation is in the form of partial differential equation, to obtain a solution it must be expressed in the form of approximate solution so that a digital computer which can perform only arithmetic and logical operations can be employed to obtain a solution. Taylor series expansion will be considered to convert these partial derivative terms in algebraic form which has been expressed [1].

Equation 4 has been adopted in the present paper as it is simple to code while equation 3 has been kept for future work.

Equation 4 can be discretized using two schemes either by explicit scheme or by implicit scheme [1].

$$\frac{T_{i,j}^{n+1} - T_{i,j}^{n}}{\Delta t} = \alpha\left(\frac{T_{i+1,j}^{n} + T_{i-1,j}^{n} - 2T_{i,j}^{n}}{(\Delta x)^2} + \frac{T_{i,j+1}^{n} + T_{i,j-1}^{n} - 2T_{i,j}^{n}}{(\Delta y)^2}\right) \quad (5)$$

$$\frac{T_{i,j}^{n+1} - T_{i,j}^{n}}{\Delta t} = \alpha\left(\frac{T_{i+1,j}^{n+1} + T_{i-1,j}^{n+1} - 2T_{i,j}^{n+1}}{(\Delta x)^2} + \frac{T_{i,j+1}^{n+1} + T_{i,j-1}^{n+1} - 2T_{i,j}^{n+1}}{(\Delta y)^2}\right) \quad (6)$$

Equation 5 and 6 represents the explicit and implicit discritization of equation 4. Explicit scheme is simple to code but requires a condition to be satisfied which is known as stability condition and leaves a limit on the time step for a particular grid selection while implicit scheme is free of this stability condition represented in eq. 7.

$$\alpha \times dt\left(\frac{1}{(dx)^2} + \frac{1}{(dy)^2}\right) \le \frac{1}{2} \quad (7)$$

In the present study explicit scheme has been considered for simplicity of the scheme, as we know that term at time 'n+1' is unknown while terms at time 'n' are known. So from above equation it can be observed that all the terms on right hand side are at time 'n' (known) while only one term at time 'n+1' is there in left hand side which can be easily calculated as,

$$T_{i,j}^{n+1} = T_{i,j}^{n} + \alpha\Delta t\left(\frac{T_{i+1,j}^{n} + T_{i-1,j}^{n} - 2T_{i,j}^{n}}{(\Delta x)^2} + \frac{T_{i,j+1}^{n} + T_{i,j-1}^{n} - 2T_{i,j}^{n}}{(\Delta y)^2}\right) \quad (8)$$

Boundary conditions

At x = 0 $\qquad q = k\frac{\partial T}{\partial x} = h_f(T - T_\infty)$

At x = L $$q = k\frac{\partial T}{\partial x} = -h_f(T - T_\infty)$$

At y = 0 $$q = k\frac{\partial T}{\partial y} = h_f(T - T_\infty)$$

At y = H $$q = k\frac{\partial T}{\partial y} = -h_f(T - T_\infty)$$

Where q = quantity of heat transfer in Joules (J), h_f = latent heat of fusion in (KJ/mol)and T_∞ = Ambient temperature in Kelvin (K)

II. RESULT AND DISCUSSION

All three phenomenons of heat transfer conduction, convection and radiation will contribute toward the solution of this problem (solidification of Al 6061 casting in green sand mould). But for the simplicity of the problem convection and radiation has been neglected.

Figure2 represents the cooling rate of the Al 6061 in the green sand. Central point temperature of the mould cavity has been plotted. As melting point temperature is 861K for Al 6061 at this temperature liquid metal is poured into the mould cavity which is initial foundry shop temperature.Temperature on the walls of the cavity is atmospheric temperature and is equal 310K. One can notice that from the figure that when time step dt is equal to '0.001' temperature is around 861K and as the time increases, temperature starts to cool down and reaches to atmospheric temperature after large number of iteration.

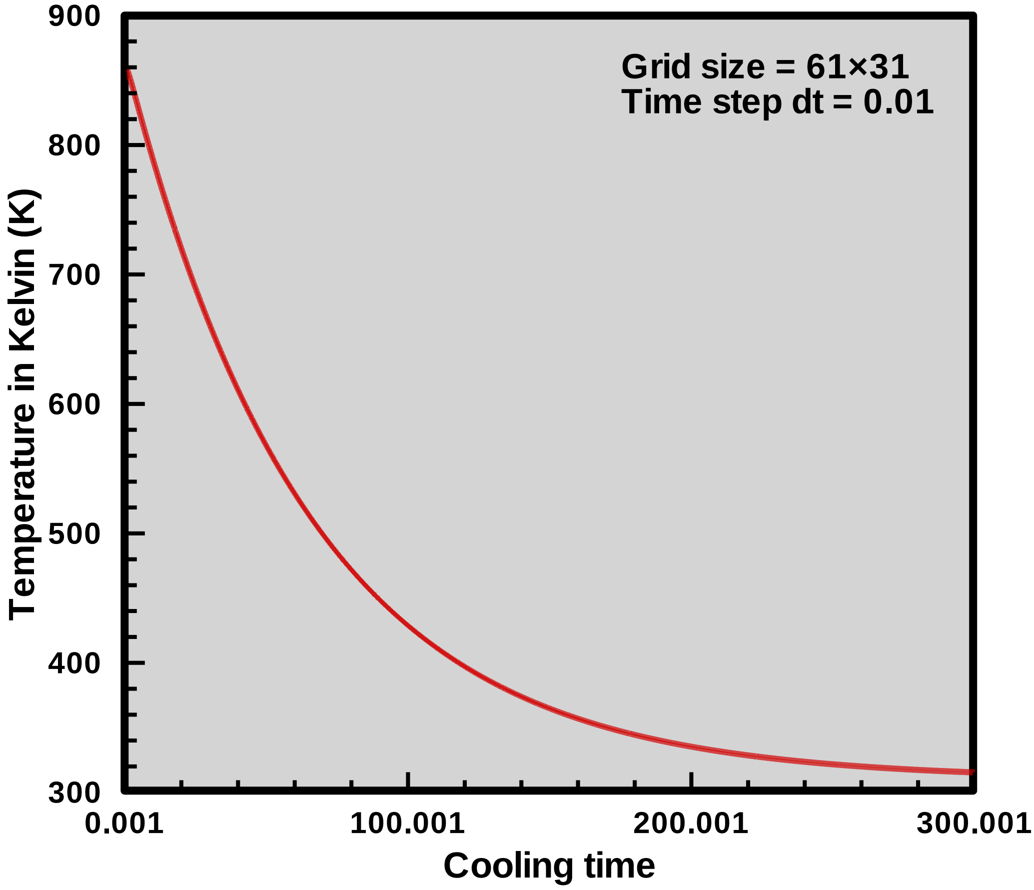

Figure 2. Cooling curve of Al 6061 in green sand mould

Figure 3 (a-c) represents the temperature distribution of Al 6061 casting in green sand mould for steady state condition for different number of iterations. One can notice that with increment in number of iteration temperature distribution is getting smoother. This temperature distribution has been plotted on a grid size of 61×31. This surf has been plotted in full part of the mould cavity, as one can notice that the maximum temperature is at the centre of the cavity from where Al 6061 is poured (861K) then it is decreasing towards the walls of the cavity in both x-direction and y-direction respectively, which are at atmospheric temperature (310K).

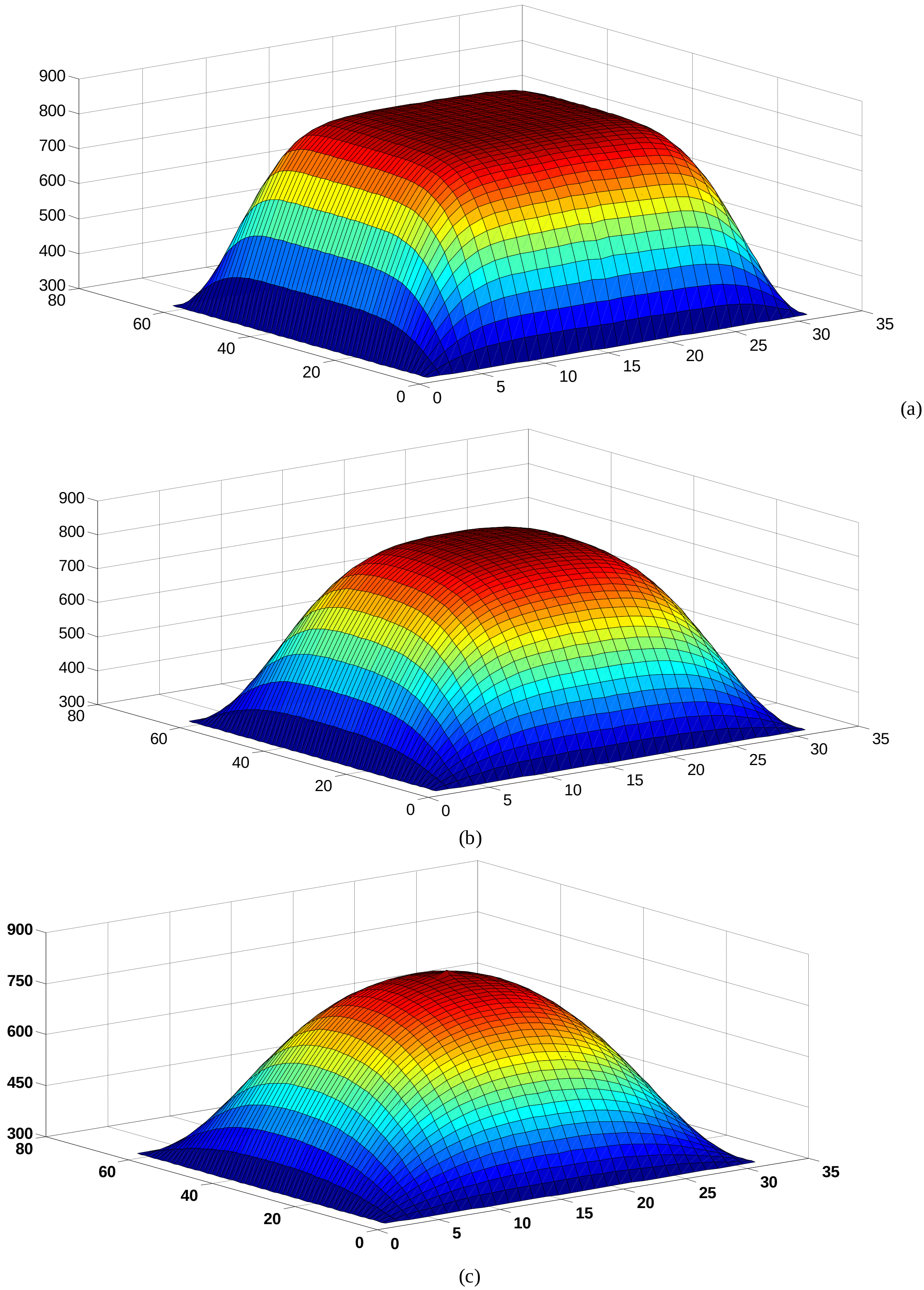

Figure 3 (a-c) Temperature distribution in casting and sand mould during solidification for number of iteration (a) 30 (b) 60 (c) 90

III. CONCLUSION

Two-dimensional heat conduction in a rectangular cavity has been solved for solidification of Al 6061 casting in green sand mould. Finite difference method (FDM) has been used to solve the equation.

- Grid size of 61×31 is found well for studying temperature distribution.
- Number of iteration smoothen the temperature distribution.
- Cooling rate in unsteady case of Al 6061 casting in the green sand mould cavity has been plotted.
- Temperature distribution in steady state case of Al 6061 casting in green sand mould.

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