Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 04, April -2018

NUMERICAL SIMULATION OF VERTICAL UP CASTED COPPER MOTHER TUBE

Parth Prajapati[1], R. G. Jivani[2], Dr. P. M. George[3], A. B. Damor[4]

[1]Research Scholar, [2]Associate Professor, [3]Professor, [4]Assistant Professor
[1,2,3,4] Mechanical Engineering Department, BVM Engineering College,V.V. Nagar, Anand, Gujarat, India

Abstract—*The vertical up casting is one of the type of continuous casting process. There are many advantages of vertical up casting process over horizontal continuous casting like space and strength. There are different materials that can be casted by this process like steel, copper etc. The work represent the numerical simulation of progressive vertical up casting with 4 mm stroke of copper mother tube. Enthalpy-Porosity technique is used via ANSYS Fluent to track mushy state. Different inferences are drawn by simulation that directional solidification is achieved and driving force of nucleation is decreasing and is dominated by growth process for grains. Temperature gradients and solidification front velocity are plotted with time and distance.*

Keywords*- Vertical up casting, Copper mother tube, Ring, Numerical simulation and Temperature contour*

I. INTRODUCTION

The process of continuous casting has many advantages over other manufacturing process of tubes like extrusion and forging. Reduction in wastage of material is major advantage over forging. Final product of continuous casting are may be in form of tube, strip, slab or plate. There is seen that much material variety are available in continuous casting like cast iron [1], copper and copper alloys [2] [3] [4] [5] [6], magnesium [7], steel [8] [9] and many others. Vertical up casting is one the type of continuous casting in which casting direction is against the gravity. One of the major advantage over horizontal continuous casting is precise use of space. Different shape and size of tubes could be casted simultaneously.

Copper mother tube manufactured by vertical up casting used in air conditioning and refrigeration industry. Graphite is best suitable material for the mold and mandrel because of its properties like high thermal conductivity, chemical inertness with respect to the material that is meant to be casted, good machinability, long life, wear and tear resistance, high melting temperature, thermal shock resistance, thermal stability, low heat capacity, self-lubricating or low friction co-efficient and high resistance to burn out and tension. This graphite mould cooled by chilled water in the assembly of mould and copper caster. Effective surface area for heat transfer is increased by creating thread passages for cooling water. Copper tube of ϕ 18.40 × 2.375 mm is manufactured systematically in a progressing way. Every time 4 mm ring is solidified first than it is pulled up by puller and cavity is filled up by molten metal.

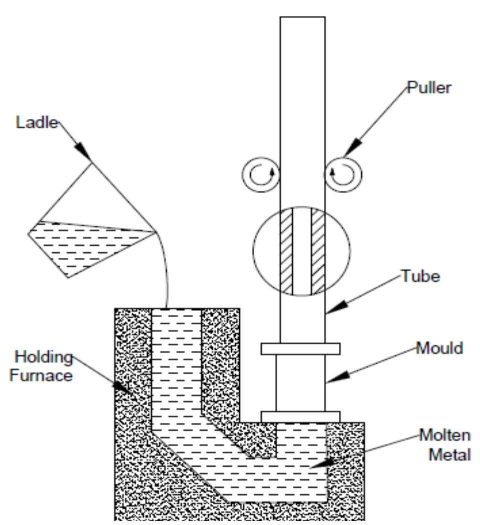


Figure 1. Vertical up casting of copper tube

Second ring solidified and joined with first ring and repeating of this phenomenon. In this way, whole tube is manufactured as shown in Figure. 2. Casting speed is 0.5 m/min. initial temperature of molten metal is 1140 °C.

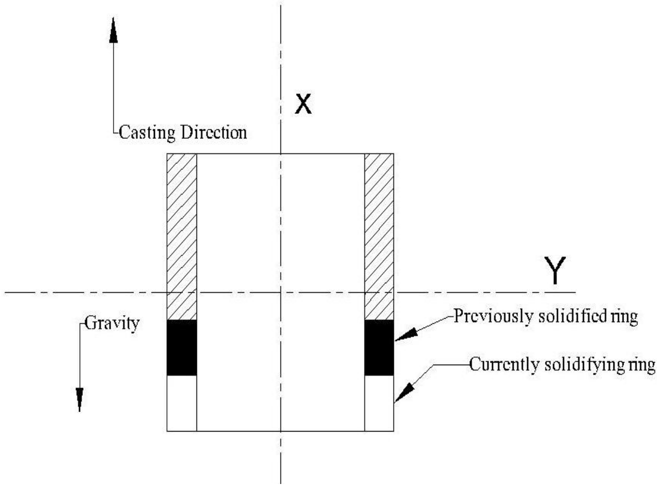


Figure 2. Copper mother tube by vertical up casting process

This paper is aimed for simulation of above-mentioned process. ANSYS Fluent software package is used for this purpose. Enthalpy-Porosity technique [10] is used for solution in which mushy state is treated as porous medium. Energy equation in solidification and melting problem is used with parameter β used for tracking of mushy region.

$$\beta = \begin{cases} 0\,, & T \geq \varepsilon \\ \dfrac{(\varepsilon - T)}{2\varepsilon}, & \varepsilon > T \geq -\varepsilon \\ 1, & T < -\varepsilon \end{cases} \tag{1}$$

Where temperature is mapped from liquidus temperature to solidus temperature as -ε to ε. For pure metal, it is very small value. As tube is axi-symmetric part, 2D analysis could fulfilled the requirement. For both one ring as well as combination of two ring is analyzed in fluent.

II. GEOMETRIC MODEL

2D geometric model is shown in fig. 3. Casting direction is in X direction where as Y direction is for thickness of wall. Farthest edge in Y direction is named as outer wall which remains in contact with high density graphite mould. Inner wall remains in contact with graphite mandrel while inlet edge always in contact with molten metal. Outlet is edge is side which is fully solidified. It would be in contact with free air. Quadrilateral elements are used for meshing. There are total 12,200 nodes and 11,880 elements meshed.

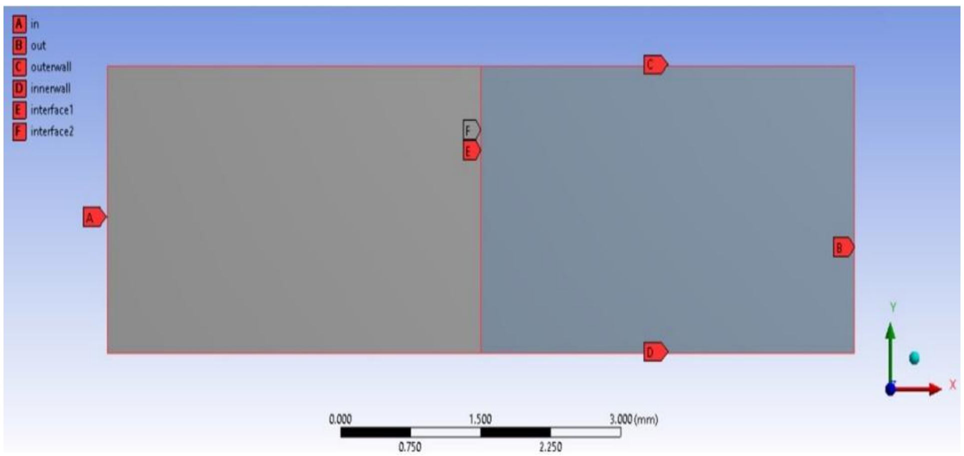


Figure 3. Geometric model of one ring

It is also objective to find out the effect of previously solidified ring on currently being solidified ring. So combination of two ring is created with interface between these two rings. It is also worth to note that previous solidified ring would not have constant temperature but different temperature gradients. So, that initial condition of temperature in previous solidified ring is applied with temperature field function. This function is created by data obtained from simulation of one ring and surface fitting tool of Matlab. Pure copper is used for casting material. The relevant properties of liquid copper and graphite is shown in table 1 and table 2.

Table 1. Material properties of liquid copper

Property	Unit	Magnitude
Density	Kg/m^3	9370 – 0.9442 T [11]
Specific Heat	J/Kg K	516.858 [11]
Thermal Conductivity	W/m K	166 [11]
Viscosity	Kg/m s	0.0044 [12]
Latent Heat of fusion	J/Kg	207000
Solidus Temperature	K	1357.77
Liquids Temperature	K	1357.77

Table 2. Material properties of high-density graphite from UCAR Graphite mould supplier

Property	Unit	Magnitude
Bulk Density	Kg/m^3	1830
Particle size Max. Min.	µm	<75 <35
Young's Modulus	Mpa	0.124
Tensile strength	MPa	31.37
Compressive strength	MPa	77.56
Permeability	Darcy's	<0.0006
Hardness	Shore Scleroscope number	50
Specific Heat	J/Kg K	720
Thermal conductivity	W/m K	100

III. INITIAL CONDITIONS, BOUNDARY CONDITIONS AND ASSUMPTIONS

Certain assumption made for simulation are following:

- It is assumed that molten metal is filled up in mould cavity with uniform initial temperature of pouring temperature 1410 K.
- No air gap generation after solidification of ring.
- Inner wall temperature is assumed constant 1300 K.
- Sp. Heat and Thermal conductivity are constant.

Molten metal temperature is 1410 K. It was assumed that inlet edge remained in contact with molten metal so constant temperature is applied. The farthest end of previously solidified ring is in contact with air. So free convection boundary condition is air stream temperature of 25 °C is applied. External graphite mould is cooled with chilled water, which has temperature of 7°C. Therefore, it iss assumed that 280 K temperature at outer wall maintained constant.

IV. RESULTS AND DISCUSSION

The result from transient analysis in fluent module of solidification\melting model is shown in Figure 4 and 5. Mass fraction value β stands 1 for liquid region and 0 for solid region as per equation 1. It could be seen that within 20 milliseconds ring is solidified. After 16 millisecond, there is not much change in solidification. Same scenario is seen in temperature gradients. There are some indirect results could be generated by this solution. It is seen in Figure 6 that difference between the temperature at solidification starts and ends is decreasing over a period. From this, it is possible to tell that driving force ΔT is decreasing over small fraction of time. Gibbs free energy required to form a stable nuclei is inversely proportional to square of ΔT. Therefore, growth would be dominant over nucleation phenomenon after very small fraction of time. From Figure 7, it can be said that thickness of mushy zone region is increasing for very small fraction because of change in heat transfer rate. It could be also possible to say from mass fraction. Because it takes more, time to solidify after certain time as seen in Figure 8.

i.
i.
v.

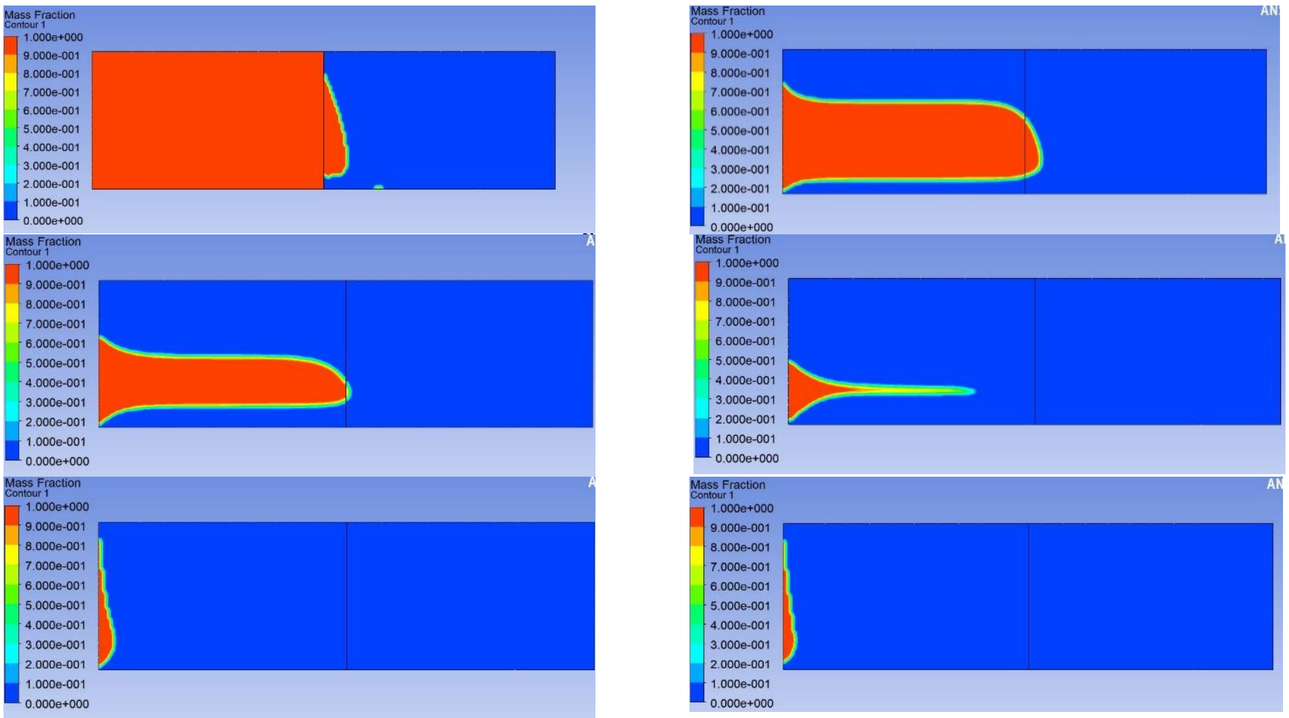
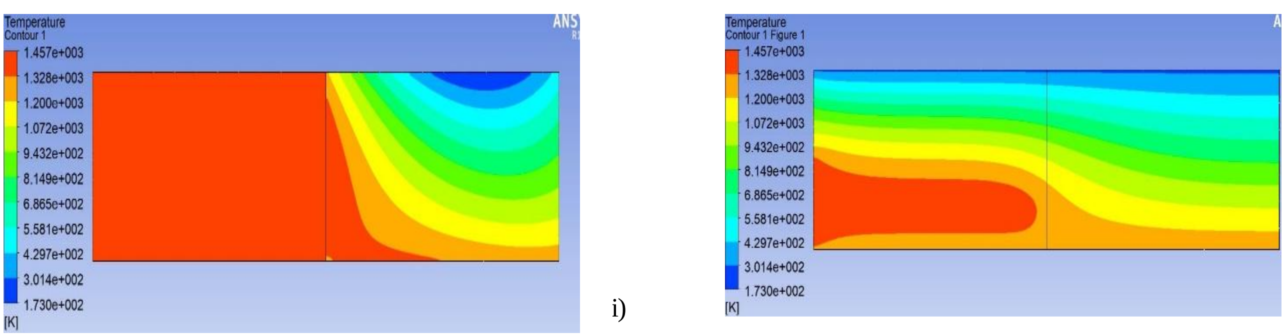
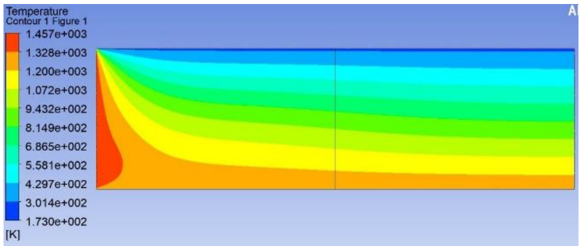


Figure 4. Mass fraction after certain interval of time (i) 0 millisecond (ii) 2 millisecond (iii) 4 millisecond (iv) 8 millisecond (v) 14 millisecond (vi) 20 millisecond

Solidification front velocity is also can be find out by noting time to achieve temperature at two points at known distance. From mass fraction variation, it could be possible to find out velocity from three sides, where solidification front is moving. From external mould wall 0.16 m/s, from interface side it is 0.1 m/s and from inner wall it is 0.08m/s. it is possible to find out instantaneous velocity as solidification front is moving from outer wall as shown in Figure 9. It is decreasing with respect to distance from external mould surface or outer wall. As shown in Figure 10 temperature gradients fixed co-ordinates over period can also be available. From that it could be seen that temperature gradient are shallow at initially in liquid zone region where as solidification front velocity or growth rate of grains is very high. It could be predicted that one ring would contain columnar dendritic structure. It is also possible to comment that grains would be slant diagonally from right most corner because heat transfer rate at outer wall and interface is more compared to inner wall as shown in Figure 11.

i)
i)



i) 

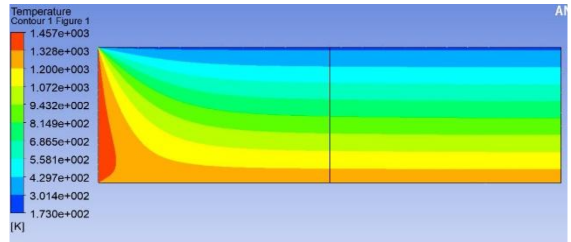
/) 

Figure 5. Temperature gradients after certain interval of time (i) 0 millisecond (ii) 6 millisecond (iii) 14 millisecond (iv) 20 millisecond

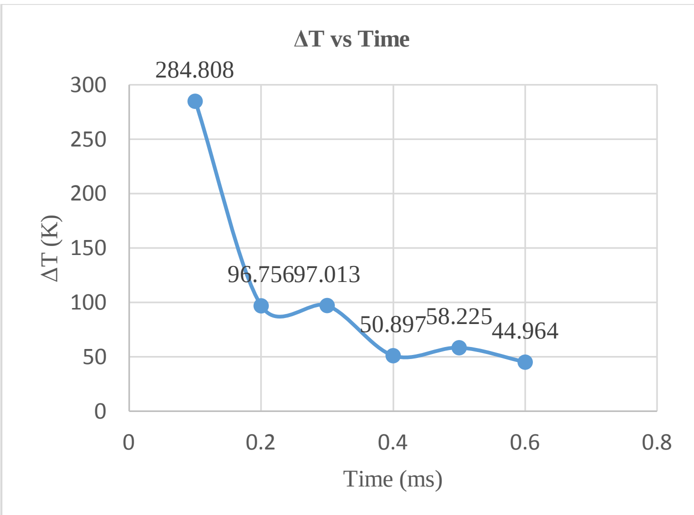


Figure 6. Temperature difference vs time

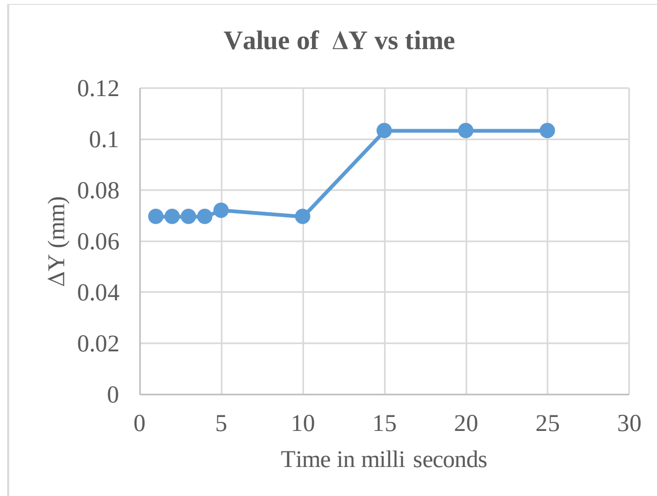


Figure 7. Thickness of mushy zone over a time

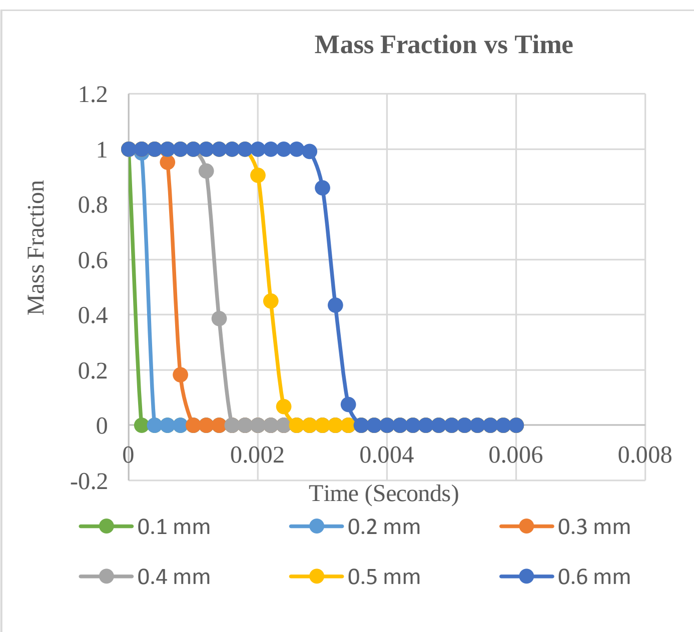


Figure 8. Mass fraction of liquid copper over time at distance from outer wall

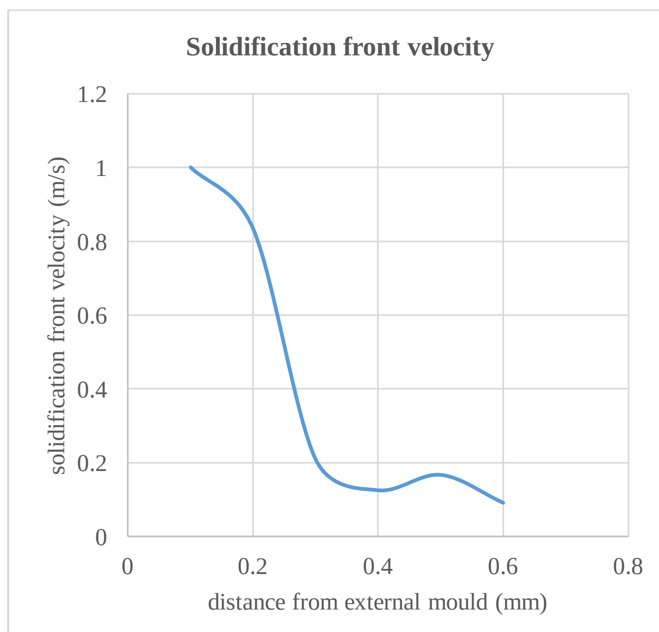


Figure 9. Solidification front velocity at distance from external wall

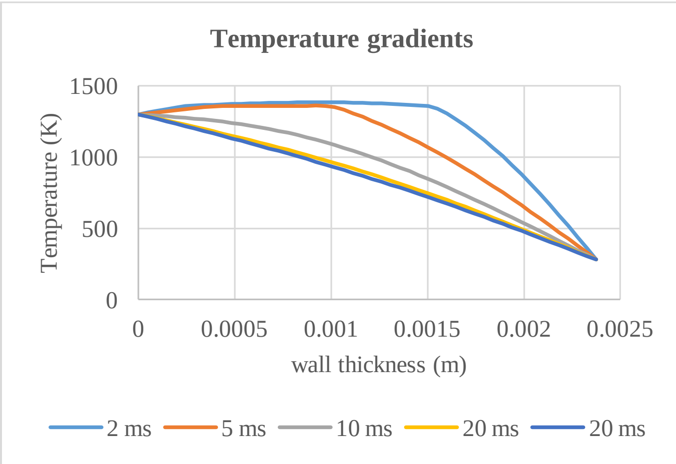


Figure 10. Temperature gradients at same location after different interval of time

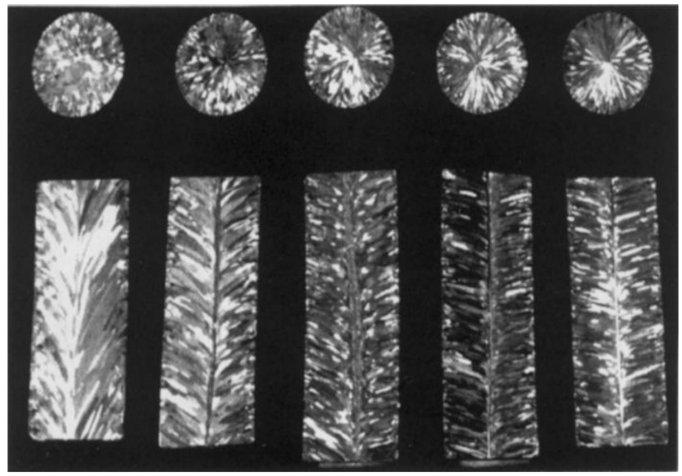


***Figure 11. Transverse and longitudinal cross sections of the copper rod with different casting speed* [13]**

V. CONCLUSION

By numerical simulation in ANSYS Fluent, temperature and liquid mass fraction can be known while solidification. Final macrostructure of product can be predicted with the direction of solidification front movement because grain growth is opposite to heat transfer. Temperature gradients and growth velocity can be computed and with help of them, macrostructure of casting can be predicted.

As the process is progressive, there is weaker section at where two rings are joint or interface is present. It is also seen that because of decrease in rate of heat transfer, there is decrement in solidification front velocity. There is also increment in time required to transformation of liquid to solid state transformation with the increment in thickness of mushy state.

REFERENCES

[1] Guojun Yan, Yang Xu, Bailing Jiang, "The production of high-density hollow cast-iron bars by vertically continuous casting," *Journal of Materials Processing Technology*, vol. 212, pp. 15-18, 2012.

[2] Yan Zhiming, Liu Hui , Li Tingju, Zhang Xiaoqing, Cao Zhiqiang, Zhang Xiaoli, "Effects of alternating magnetic field and casting parameters on solidification structure and mechanical properties of copper hollow billets," *Materials and Design*, vol. 30, pp. 1245-1250, 2009.

[3] Xi Shen, Hong Zhang, Zi-dong Wang, Hua-fen Lou, Yi-ming Jia, Ping-xia Hu, "Macrostructure and properties of thin walled copper tubes prepared by the downward continuous unidirectional solidification method," *International Journal of Minerals, Metallurgy and Materials*, vol. 17, no. 1, pp. 63-68, February 2010.

[4] Seshadev Sahoo, Amitesh Kumar, B. K. Dhindaw & Sudipto Ghosh, "High Speed Twin Roll Casting of Aluminum-Copper Strips with Layered Structure," *Materials and Manufacturing Processes*, vol. 28, pp. 61-65, 2013.

[5] Seshadev Sahoo, Sudipto Ghosh, "Microstructure evolution of eutectic Al–Cu strips by high-speed twin-roll strip casting process," *Applied Physics A, Materials science & Processing*, vol. 121, pp. 45-50, 2015.

[6] Li Xintao, Guo Zhaoxiang, Zhao Xiangwei, Wei Bi, Chen Fengbao , Li Tingju, "Continuous casting of copper tube billets under rotating electromagnetic field," *Materials Science and Engineering A*, pp. 648-651, 2007.

[7] T. Haga, H. Watari, S. Kumai, "High speed roll casting of Mg alloy strip by a vertical type twin roll caster," *Journal of achievements in Materials and Manufacturing Engineering*, vol. 15, no. 1-2, pp. 186-192, 2006.

[8] B. G. T. Chunsheng Li, "Thermomechanical Finite-Element Model of Shell Behavior in Continuous Casting of Steel," *Metallurgical And Materials Transactions B*, vol. 35B, pp. 1151-1172, 2004.

[9] R. PYSZKO, M. PŘÍHODA, P. FOJTÍK, M. KOVÁČ, "Determination of heat flux layout in the mould for continuous casting of steel," *METALURGIJA*, vol. 51, no. 2, pp. 149-152, 2012.

[10] V.R. VOLLER, C. PRAKASH, "A fixed grid numerical modelling methodology for convection-diffusion mushy region

phase-change problem," *International Journal Heat Mass Transfer*, vol. 30, no. 8, pp. 1709-1719, 1987.

[11] "http://tpds.db.aist.go.jp/tpds-web/index.aspx?MaterialID=1323," [Online].

[12] J. H. Hildebrand, R. H. Lamoreaux, "Viscosity of liquid metals: An interpretation," 1976.

[13] K. Härkki And J. Miettinen, "Mathematical Modeling of Copper and Brass Upcasting," *Metallurgical And Materials Transections B* , vol. 30, no. B, pp. 75-98, 1998.

