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MATHEMATICAL MODELLING OF TWIN ROLL CASTING OF LEAD ALLOY STRIP

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Abstract:-

The properties of lead alloys strip directly affected by the thermodynamic properties of continuous casting process which is also known a twin roll casting process. The thermal behaviour of twin roll casing process also affect the production efficiency .In twin roll casting process there may be the flowing parameter that affect the quality of the strip roll thickness , casting speed, pouring temperature of molten lead alloy, molten pool depth. For the process analysis firstly needs to build thermodynamic model & then simulate the process for thermodynamic behaviour. The process parameter of cast rolling strip can be obtained through thermodynamic research & analysis. The parameter given as roll thickness 8-9mm, casting speed 2.5-3 m/min, pouring temperature of molten lead alloy 360-400^{0}C, molten pool depth 250-300 mm. Based on the orthogonal experiments above parameters can be optimized as roll thickness 8.5-9mm, casting speed 2.75-3 m/min, pouring temperature of molten lead alloy 375-400^{0}C, molten pool depth 285-300 mm.

In this research the thermal behaviour of lead tin alloys on twin roll casting carried out & optimal process parameter is obtained which provide an effective theoretical guide for casting of lead tin alloys.

Keyword*- Twin roll casing, lead alloy strip, parameter, optimal thermodynamic behaviour.*

Introduction:-

Nowadays in cupper & zinc industries the lead alloys are widely used. The lead alloys have the wide range of mechanical & electrical properties that has the direct impact on consumption of energy & service life of anode. To increase the anode life & reduce energy consumption various methods like plating, sand blasting, shot peening are carried out. But these methods increased the additional energy consumption. So TRC methods that improve the mechanical properties reduce the micro structural defect at the same time. In the TRC the corrosion resistance will also improve the oxygen evolution potential. That could enhance the electrochemical properties of alloy. TRC process improved the capacity of production of lead alloys in the economical way. In comparison with conventional strip forming process the TRC is more economical & energy efficient due to saving of process steps. In TRC process it combines the casting & rolling together & produced improved microstructure strip. In this paper the TRC process & quality of strip are mainly focused. In the TRC the parameters that can affect the process is pouring temperature of lead alloy, casting speed, molten pool, and molten pool depth are under the study in this paper with the use of '**COMSOL MULTIPHYSICS**'. The TRC process parameters are optimized in this research compared to conventional process parameter.

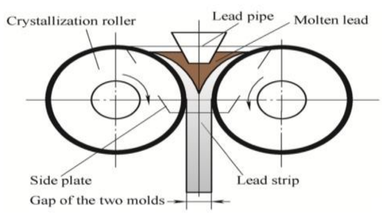


Fig. 1 Schematic diagram of TRC

Thermodynamic model:-

In the TRC process the molten lead alloys pulled at certain speed between the gap of two mould. During the process heat transfer from the molten lead pool to rolls depends upon physical properties of lead alloy & boundary conditions of rolls. Assuming that the lead tape thickness in the x direction, width in y direction & casting in z directions. The temperature distribution along x,y,z directions is T.

The twin roll casting has the following assumption as-

(i) The density in each phase is constant.

(ii) The influence of latent heat of phase change is neglected.

(iii) All the phases during the process considered in same continuum.

Now from the Fourier law of heat conduction the three dimensional heat transfer equation of slab solidification is given as-

$$0= \rho c \frac{\partial T}{\partial t} - \rho v c \frac{\partial T}{\partial z} - \frac{\partial}{\partial x}\left(\mu \frac{\partial T}{\partial x}\right) - \frac{\partial}{\partial y}\left(\mu \frac{\partial T}{\partial y}\right)$$

Again from the Kirchhoff equation,

$$\Phi = \int_{T0}^{T} \frac{\mu(T)}{\mu o} dT \qquad \text{(ii)}$$

$$H= \int_{To}^{T} C(T)dT \qquad \text{(iii)}$$

Where

Φ= transformation temperature

λ(T)= thermal coefficient

λ_0= heat conductivity at 0^0C

H= enthalpy (transition)

C(T)= specific heat at temperature T

Putting the values of equation (i) & (ii) in equation (i)

$$\rho \frac{\partial H}{\partial T} = \rho v \frac{\partial H}{\partial Z} + \mu o\left(\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2}\right)$$

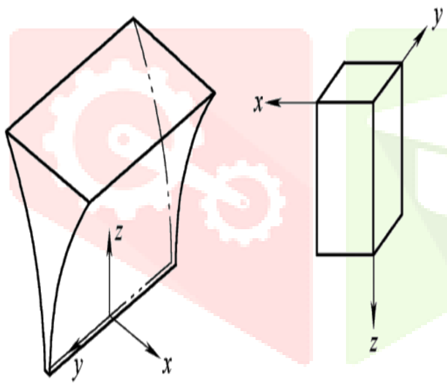


Fig. 2 Diagram for Coordinate

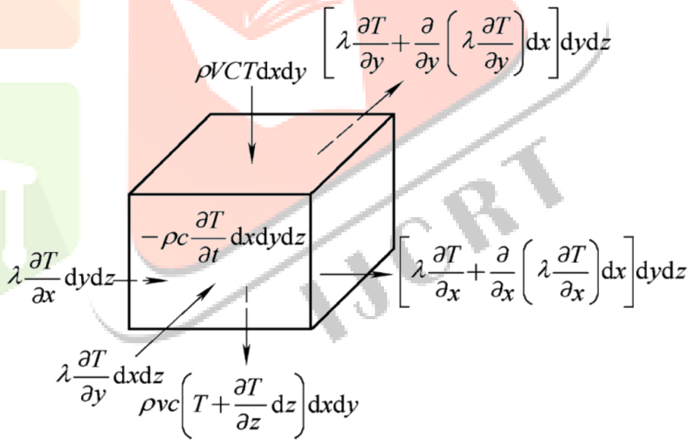


Fig 3 Space element diagram

Initial conditions:-

$T=T_0$ ($x\geq0$, $y\geq0$, $z\geq0$, $t\geq0$)

$T(x,0,0)|_{x=o}= T_b(t=0)$

$X_s|_{t=0}=0$

Where,

T_o- Pouring temperature in ^{0}C

T_b- Surface temperature of casting in ^{0}C

X_s- Thickness of casting solidification in m.

Boundary conditions:-

The high speed of cooling water taken away heat from the molten lead the average heat flux density of roller cooling can be given as-

$$q = \frac{Qw \times Cw \times \Delta Tw}{F}$$

where,

q=average heat flux density w/m^2

Q_w= cooling water flow rate, m^3/s

ΔT_w= difference of water temperature in & out

F= effective heating area

Geometric model:-

Twin roll casting lead area is made up of two relative motion of sealing plate & forming rollers.Material parameter-

The lead alloys is Pb-Ag-Ca is used for experimental material. The chemical composition are given as follows-

ω (Pb) = 97%-98%

ω (Ag) = 1.5%-2%

ω (Sn) = 0.006%

ω (Ca) = 0.08%

ω (Sb) ≤ 0.02%

ω (Cu) ≤ 0.06%

ω (Fe) ≤ 0.012%

ω (Bi) ≤ 0.03%

ω (As) ≤ 0.02%

In this research paper temperature is used as function of material thermal properties & expressed as follows for simulation-

Density $\rho = 11113.6 - 1.34T$ (kg/m^3)

Specific heat capacity: $C_p = 246.8 \times T^{-0.08}$ (J/Kg.K)

Viscosity: $\eta = 4.94 \times 10^{-4} \times e^{(\frac{757.1}{T})}$ (Pa.s)

Heat conductivity: $\lambda = 4.21 + 1.2 \times 10^{-2}.T$ (W/mK)

T- Temperature in K

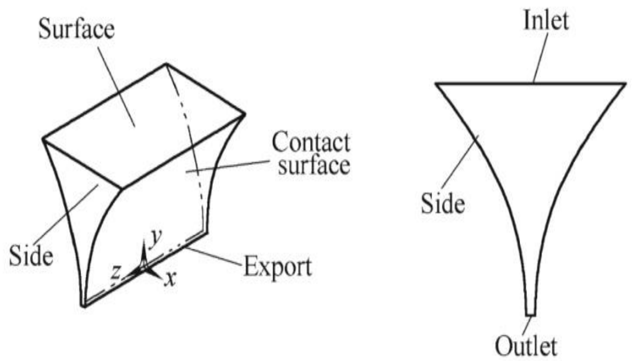


Fig 4 TRC model

Mesh Generation:-

In comparison to pure metal the alloys have undergone various temperature transition phases. During the process alloys coexist in solid & molten state simultaneously called mushy zone. The dimension of geometric model is shown below.

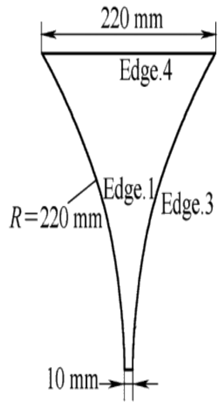


Fig 5 Dimension of geometric model

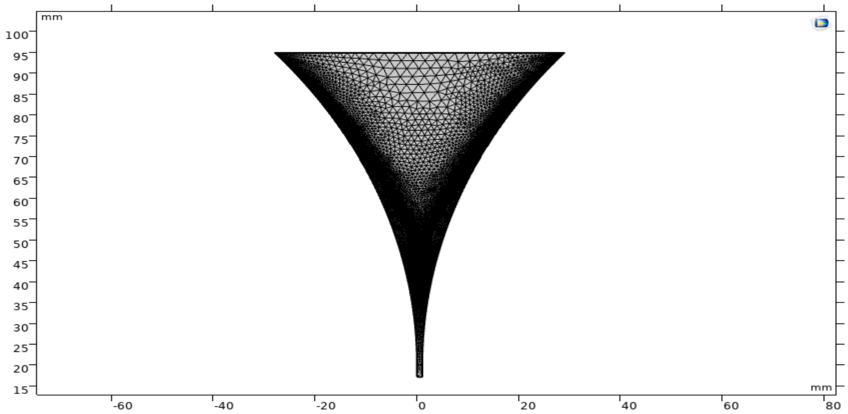
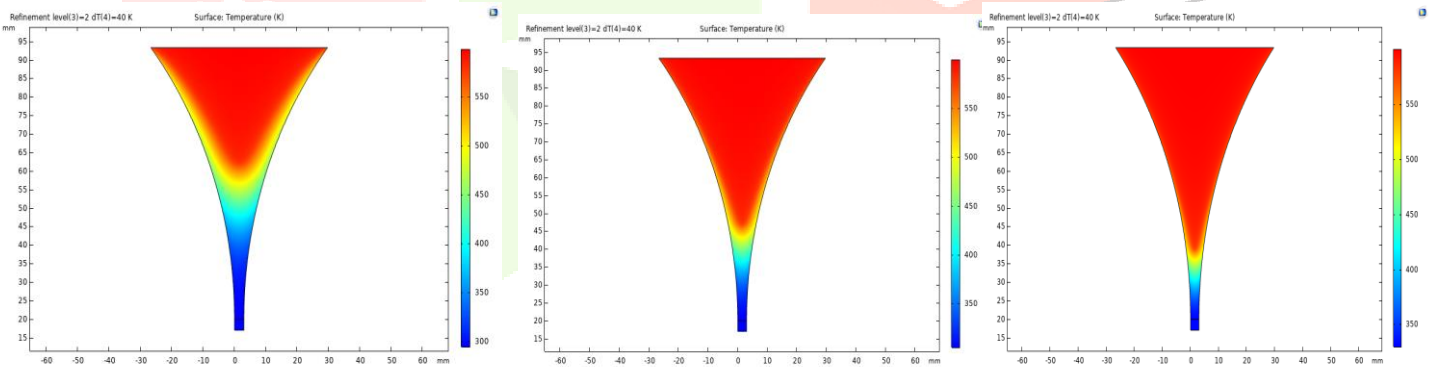


Fig 6 Mesh generation result

Simulation analysis:-

Effect of pouring temperature:-

Considering the conditions for simulation are the depth of molten pool is 300 mm, roll casting speed is 3m/min, rolling thickness is 9mm & pouring temperature are 360^0, 400^0, 440^0. It can be analysed from the figure below that increase of pouring temperature the high temperature in molten lead pool is gradually close to the outlet & when pouring temperature is too low causes high position of solidification & rolling force will increase which is adverse to twin roll casting process. From the figure it is analysed that when the pouring temperature increases, the cross section of rolling pressure will get reduced. Meanwhile the rolling pressure will also get reduced & move to outlet of casting area.



(i) 360^0C (ii) 400^0C (iii) 440^0C

Fig 6 effect of different pouring temperature on TRC

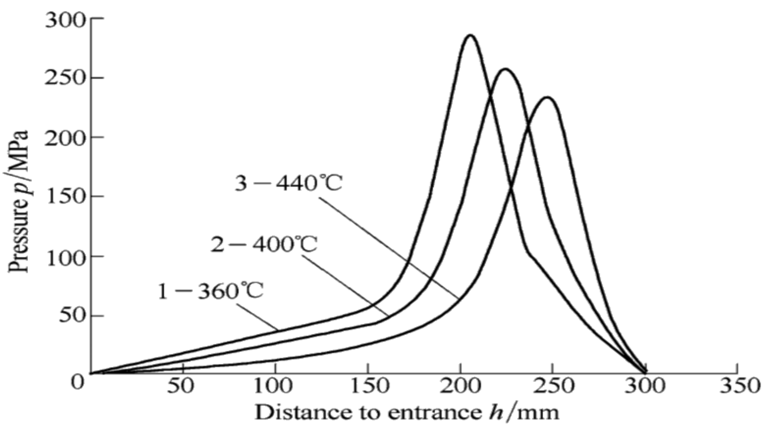


Fig 7 Effect of pouring temperature on roll pressure

Effect of rolling thickness:-

With increase of rolling thickness the high temperature is gradually close to the outlet causes the solidification remains incomplete. Due to incomplete solidification the strip will have low strength & broken strip. The rolling peak is also reduced due to increase of rolling thickness.

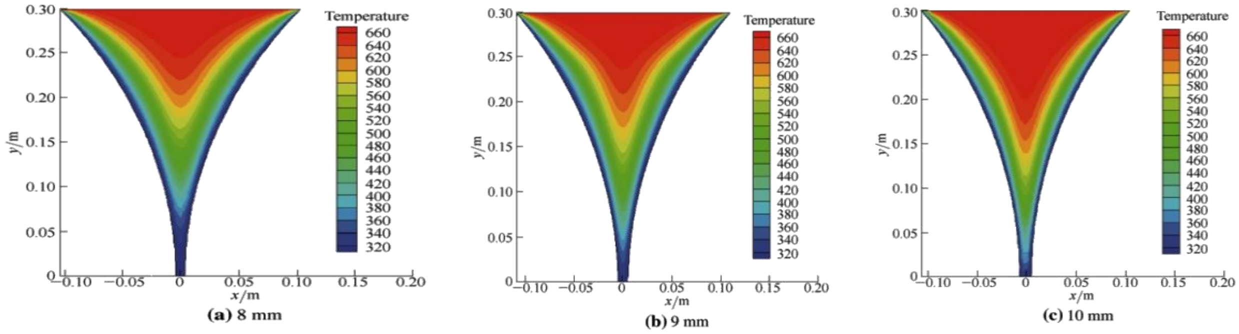


Fig 8 Effect of roll thickness on TRC

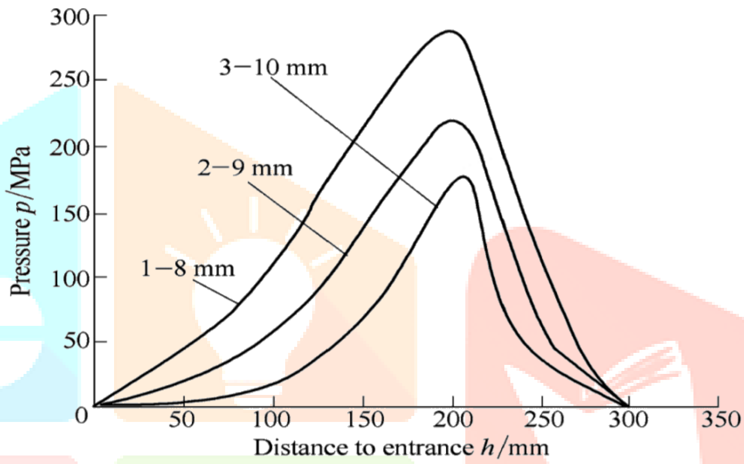


Fig 9 Roll thickness effect on roll pressure

Effect of roll casting speed:-

It is observed from the simulation that increase of roll casting speed the high temperature in molten pool gradually close to outlet & thickness of strip get reduced. The solidification time of strip get reduced with increase of casting speed. If casting speed increases the pressure peak & rolling pressure will also get reduced.

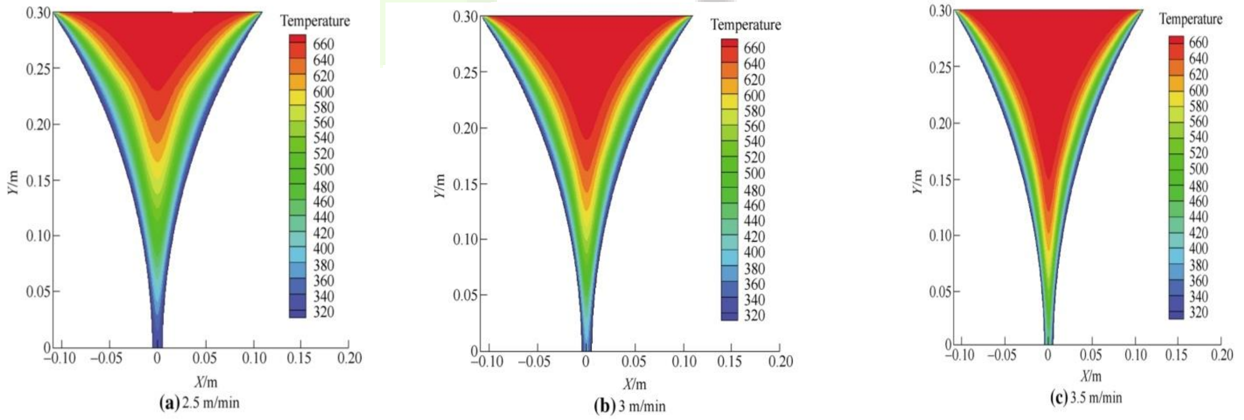


Fig 10 Effect of casting speed on TRC

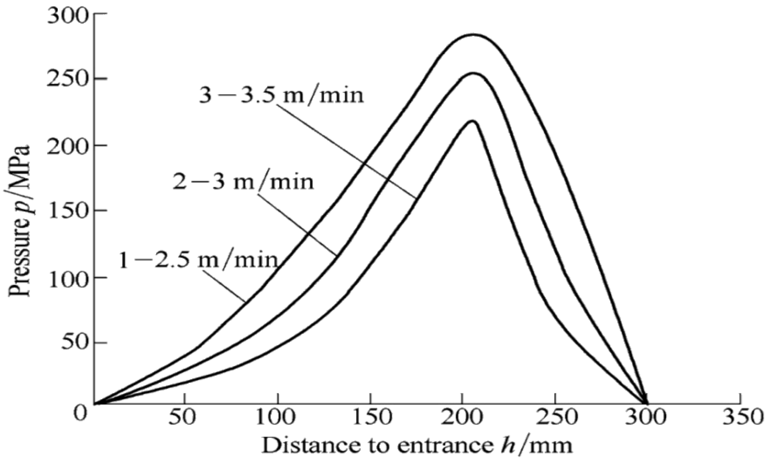


Fig 11 Effect of roll casting speed on roll pressure

Effect of depth of molten pool:-

If the molten pool depth increases the high temperature in the molten pool gradually close to outlet. But in case of low depth the local temperature dropping very fast & after that the casting process obstructed. If the molten pool depth in reducing then rolling pressure is also decreasing at the same cross section.

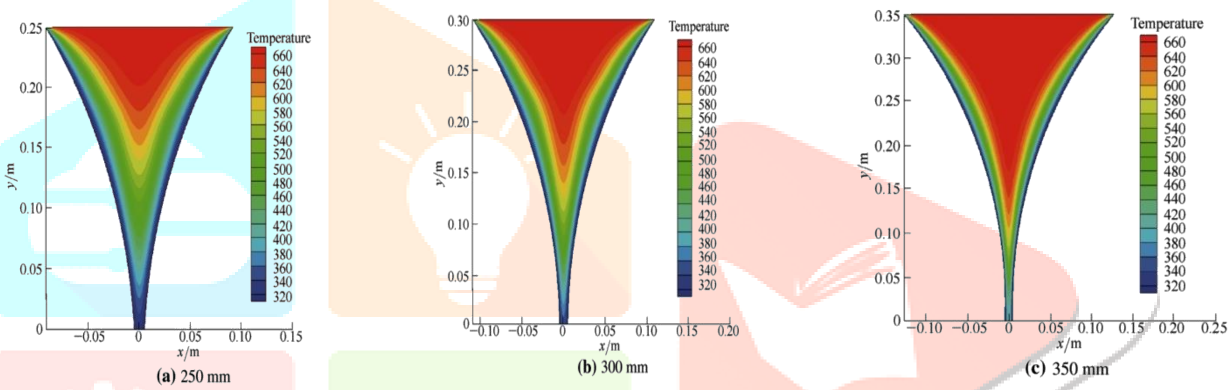


Fig 12 Effect of depth of molten pool on TRC

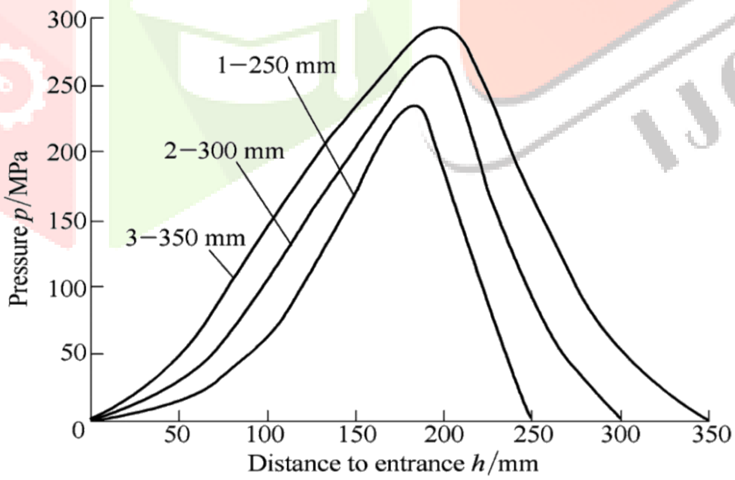


Fig 13 Effect of depth of molten pool on roll pressure

Conclusion:-

In this study the thermodynamic model has been setup & different process parameter which is optimized for each process is obtained. By this analysis it is proved that the thermodynamic model is efficient correct have better conductivity & higher mechanical performance as compared to multi pass rolling process.

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