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Analysis of Temperature loss of Hot Metal during Hot Rolling Process at Steel Plant

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Abstract: *Hot metal is travelling a long distance (around 126 m) between roughing mill and a Steckel finishing mill during hot rolling process in a steel plant which resulted in heat loss. Since, the metallurgical qualities of finished product are closely related to the accurate control of temperature of the material during the hot rolling process, the heat in the furnaces maintains the slab temperature at high level at the cost of more fossil fuels. Temperature of the work piece influences spread appreciably. Lower the temperature of raw material input, greater is the spread. Similarly, higher the temperature, lesser is the spread. Lesser speed of rolling results in greater spread and vice-versa. Hence, temperature is playing a vital role in hot rolling process.*

Temperature loss of semi finished work pieces between the mill stand is inevitable until it protected from the open atmosphere. If a low-emissivity material (radiation shield) is placed between two surfaces, the radiation heat transfer can be considerably reduced. The shield increases the thermal resistance to radiation heat flow. Because radiation is a major source of heat loss at the temperatures involved (around 1060° C.) Thermal shields may be fixed over the path of the hot strip to reduce heat loss and in particular such heat shields can be employed to reduce the head-to-tail temperature variation along the length of a transfer bar. The result of this study is the development of an effective procedure for computer calculation of processes of hot rolling to optimize its parameters

Key words: *Heat loss, Convection and radiation heat transfer, thermal shield, temperature gain*

I. Introduction

The semi-finished steel products from the casting operations are further processed to produce finished steel products in a series of shaping and finishing operations in the rolling mills. Rolling mills are either hot or cold processes. Mechanical forces for cold rolling will create much more force and energy needs, while hot rolling happens much faster with less force. However, there are significant energy costs to heat the metal to near eutectic temperatures. Hence, this study is concern with TWO main objectives:

- To minimize temperature loss of hot metal while it is conveyed from rougher to finishing mill.
- To decrease the temperature difference of head and tail end of hot metal on entering the finishing train.

In order to achieve the proposed objective, the following main tasks are included in this study:

- Calculating the heat loss of the hot metal from the walking beam furnace.
- Calculating the heat loss of the hot metal (Transfer Bar) travelling between the Reheat furnace and roughing Mill which includes the:
- Temperature drop due to radioactive heat transfer between the slab and the surrounding environment.
- Temperature drop due to heat Convection between the slab and air.
- Calculating the **EXPECTED** Heat loss from **Transfer Bar** if the **THERMAL SHIELD** is placed over the distance between Roughing Mill and finishing mill.
- Comparing the results and calculating the exact amount of heat gain by introducing this innovative technique.

II. Heat Transfer Calculation

Radiation shield and the radiation effect

Radiation heat transfer between two surfaces can be reduced greatly by inserting a thin, (low-emissivity) sheet of material between the two surfaces. Such highly reflective thin plates or shells are called **radiation shields.** The role of the radiation shield is to reduce the rate of radiation heat transfer by placing additional resistances in the path of radiation heat flow.

Radiation heat transfer between two large parallel plates of emissivity's ε_1 and ε_2 maintained at uniform temperatures T_1 and T_2:

A thin carbon steel sheet with an emissivity of 0.56 is placed between the hot slab and atmosphere that are maintained at uniform temperatures $T1$ = 1050°C and T_2 = 30°C and have emissivities $\varepsilon_1 = 0.56$ and $\varepsilon_2 = 0.56$, respectively. Determine the net rate of radiation heat transfer between the hot slab and atmosphere and compare the result to that without the shield.

DATA of the hot metal slab considered for Analysis

Size of the hot metal slab = 1.275 m X 60 m

Area of the slab = 76.5 m^2

Approximate distance travelling by hot metal Transfer bar between roughing mill and a STECKEL finishing mill = 126 m

Velocity of the hot metal = 3.5 m/sec

Weight of the material = 15,000 kg

Mean specific heat = 0.483 kJ/kg°K

Temperature of the coming out of Roughing mill =1050°C

Ambient temperature =30°C

The quantity of heat available with hot slab coming out of roughing Mill (Q) can be found from the formula (Assuming ONE DIMENSIONAL heat flow).

$$\mathbf{Q = m \times C_p (t_1 - t_2)}$$

Where

Q = Quantity of heat in kJ

m = Weight of the material in kg

C_p = Mean specific heat, kJ/kg°K

t_2 = Ambient temperature, °K

t1 = Temperature of the slab coming out of the roughing mill °K

Hence, The quantity of heat available with hot slab coming out of roughing Mill

(Q) = m x C_p $(t_1 - t_2)$

= 15,000 X 0.483 (1050 – 30)

= 73,89,900 kJ

III. Calculation Of Heat Loss Without Thermal Shield

Researchers working in the field of hot rolling have classified the heat transfer mechanism involved in the process are as follows:

1. Temperature drop due to radiation heat transfer between the slab and the surrounding environment.
2. Temperature drop due to heat convection between the slab and air

Heat loss due to radiation heat transfer between the hot metal and the surrounding environment:

If a hot object is radiating energy to its cooler surroundings the net radiation heat loss rate can be expressed as

$$q = \varepsilon \sigma (T_h^4 - T_c^4) A$$

where

T_h = *hot body absolute temperature (K)*

T_c = *cold surroundings absolute temperature (K)*

A = area of the object (m^2)

The emissivity of steel at *390 °F (199 °C) > ε = 0.64*

$\sigma = 5.6703 \times 10^{-8}$ (W/m^2K^4) - *The Stefan-Boltzmann Constant*

In our case to calculate heat loss rate on both sides of hot metal

$$\mathbf{q = 2 \times \varepsilon \sigma (T_h^4 - T_c^4) A}$$

$= 2 \times 0.64 \times 5.6703 \; 10^{-8} \; W/m^2K^4 \times (1323^4 - 303^4) \times 76.5$

≃ 16964 KW ------------ (a)

Heat loss due to heat convection between the hot metal and air;

Let us assume the FORCED CONVECTION FOR FLAT PLATE for our case:

Flow over flat plate

The friction and heat transfer coefficient for a flat plate can be determined by solving the conservation of mass, momentum and energy equations (either approximately or numerically). They can also be measured experimentally. It is found that the Nusselt number can be expressed as:

$$\mathbf{Nu} = \frac{hL}{K} = C\, Re^{m}\, Pr^{n}$$

Where C, m and n are constants and L is the length of the flat plate. The properties of the fluid are usually evaluated at the film temperature defined as:

$$T_f = \frac{TS + T\alpha}{2}$$

Turbulent flow

For isoflux plates, the local Nusselt number for turbulent flow can be found from

$$\mathbf{Nu} = \frac{hL}{K} = 0.037 \times Re^{4/5} \times Pr1^{/3},$$

$$0.6 \leq P_r \geq 60,\ 5 \times 10^5 \leq Re \geq 10^7$$

(The above relationships have been obtained for the case of isothermal surface but could also be used approximately for the case of non-isothermal surface. In such cases assume the surface temperature be constant at some average value**)**

Reynolds number: Ratio of inertia forces to viscous forces in the fluid

$$\mathbf{Re} = \frac{\rho LV}{\mu}$$

Properties of Air, (1050 + 30)/2 = 540ºC

From the HMT Table for Air temperature 540ºC;

Density (ρ) = 0.4352 kg/m^3
Specific heat (**Cp**) = 1.101 kJ/kg ºk
Coefficient of viscosity (**μ**) = 37.37 X 10^{-6} kg/ms
Kinematic viscosity (**ϑ**) = 86.38 X 10^{-6} m^2/sec
Thermal conductivity (**k**) = 59.36 X 10^{-3} W /m ºk
Prandtl Number (**Pr**) = 0.704

Hence,

$$\mathbf{Re} = \frac{\rho LV}{\mu}$$

$$= \frac{0.432 \times 60 \times 3.5}{37.37 \times 10^{-6}} = \mathbf{2.45 \times 10^6}$$

Flow is TURBULENT, since the Re is > the critical Reynolds number 5 X 10^5

For isoflux (uniform heat flux) plates, the local Nusselt number for turbulent flow:

$$\mathbf{Nu = 0.037 \times Re^{4/5} \times Pr^{1/3}}$$

$$= 0.0308 \times (2.45 \times 10^6)^{4/5} \times (0.704)^{1/3}$$

$$\mathbf{= 4258}$$

$$\mathbf{Nu} = \frac{hL}{K} = 0.037 \times Re^{4/5} \times Pr^{1/3} \text{ (for cooling)}$$

$$\frac{hL}{K} = 4258$$

$$h = \frac{4258 \times 59.36 \times 10^{-3}}{60} = \mathbf{4.21\ W / ^{o}C}$$

Therefore the HEAT loss on both sides of Hot metal due to convection:

$$\mathbf{Q_{con} = 2 \times h \times A\ (\Delta T)}$$

$$= 2 \times 4.21 \times 76.5 \times (1050 - 30)$$

= 657 kW -------------------- (b)

For Total Heat Loss from hot metal

= (a) + (b) = 16964 + 657 = **17621 kJ/sec.**

IV. Calculation Of Heat Loss With Thermal Shield

Specification of Thermal shield:
Shape of the shield proposed: Rectangular shield Size of the shield:1.5 m (W) X 2.0 m (L) X0.5 m (H)
Area covered under the shield : Length of the transfer bar (60 m)

Heat loss due to radiation heat transfer between the hot metal and the surrounding environment:
To calculate radiation exchange we must take into account surface areas, surface geometries and position in relation to each other.

This is done by the *shape factor F12*
F12 = Fraction of Radiation leaving surface 1 and interrupted by surface 2
Net exchange of RADIATION between the surfaces of ***two parallel infinite plates***
If Emissivity's are equal

$$\frac{q}{A} = \frac{\sigma\,(T_1^{\,4} - T_2^{\,4})}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Where
Stefan Boltzmann's Constant (σ)
= $5.67\,X10^{-8}$ Wsk^{-4}/m^2
$Emissivity\ of\ Steel\ slab\ \varepsilon_1$ = 0.56,
Temperature T_1 = 1050ºC
$Emissivity\ of\ Steel\ plate\ \varepsilon_2$ = 0.56,
Temperature T_2 = 930ºC
Area of the shield (A)
= (1.5 X 62) + (0.5 X 62) + (0.5 X 62)= 155 m^2

$$\frac{q}{A} = \frac{5.67\,X10^{-8}\,(1323^4 - 1203^4)}{\frac{1}{0.56} + \frac{1}{0.56} - 1}$$

q = 155 X $\frac{5.67\ X\ 10^{-8}\ X\ 9692\ X\ 10^{8}}{2.57}$ = 3314325

Heat loss on both side of Hot metal (q)
= 2 X 3314325 = 6628649 watts
Radiation heat loss (q) = 6628 K --------- (c)

Heat loss due to heat convection between the hot metal and air;
Properties of Air, (1050 + 930)/2 = 990ºC
From the HMT Table for Air temperature 1000ºC ;
Density (**ρ**) = 0.277 kg/m^3
Specific heat (**Cp)** = 1.185 kJ/kg ºk
Coefficient of viscosity (**μ**) = 49.03 X 10^{-6} kg/ms
Kinematic viscosity (**ϑ**) = 178.00 X 10^{-6} m^2/sec
Thermal conductivity (**k**) = 80.71 X 10^{-3} W /m ºk
Prandtl Number (**Pr)** = 0.719
Velocity of Transfer bar = 3.5 m/sec
Hence, **Re** = $\frac{\rho\,LV}{\mu}$ = $\frac{0.277\ X\ 62\ X\ 3.5}{49.03\ X\ 10^{-6}}$ **= 1.225 X 10^6**
Flow is TURBULENT, since the Re $_{is}$ > the critical Reynolds number 5 X 10^5
For isoflux (uniform heat flux) plates, the local **Nusselt number for turbulent** flow:
Nu = 0.037 X Re$^{4/5}$ x Pr$^{1/3}$
= 0.037 X (1.225 X 10^6)$^{4/5}$ X (0.719)$^{1/3}$ = 2463
Nu = $\frac{hL}{K}$ = 0.037 X Re$^{4/5}$ x Pr$^{1/3}$ (for cooling)
$\frac{hL}{K}$ = 2463
h = $\frac{2463\ X\ 80.71\ X\ 10^{-3}}{62}$ **= 3.20 W / ºC**
Therefore the HEAT loss on both sides of Hot metal due to convection:

Q_{con} = 2 X h X A (ΔT)
= 2 X 3.20 X 155 X (1050 – 930)
= 119 kW ------------------------ (d)
For Total Heat Loss from hot metal
= (c) + (d) = 6628 + 119 = 6747 Kw **= 6747 kJ/sec.**

V. Temperature Available In The Transfer Bar *Without* Thermal Shield

Time taken by the Head end to reach Steckel mill (T_h) = $\frac{126}{3.5}$ sec = 36 Sec
Time taken by the Tail end to reach Steckel mill (T_t) = 53 sec
Heat Loss in Transfer Bar Head end
= 17621 X 36 sec = **634356 KJ**

Heat Loss in Transfer Bar Tail
= 17621 X 53 sec **= 933913 KJ**

Temperature available in the transfer bar at head end
(Q)= m C_p ΔT
The quantity of heat available with hot slab coming out of roughing Mill
(Q) = m x Cp (t_1 – t_2)
= 15,000 X 0.483 (1050 – 30)
= 73, 89,900 kJ
Hence, 7389900 (-) 634356
= 15,000 X 0.483 (T_h – 30), Th **= 962** ℃

Temperature available in the transfer bar at tail end
(Q) = m C ΔT
Hence, 7389900 (-) 933913
= 15,000 X 0.483 (T_t – 30), **T_t = 921** ℃

VI. Temperature Available In The Transfer Bar *With* Thermal Shield

Time taken by the Head end to reach Steckel mill (T_h) = $\frac{126}{3.5}$ sec = 36 Sec
Time taken by the Tail end to reach Steckel mill (T_t) = 53 sec
Heat Loss in Transfer Bar Head end
= 6747 X 36 sec = **242892 KJ**
Heat Loss in Transfer Bar Tail end
= 6747 X 53 sec = **357591 KJ**

Temperature available in the transfer bar at head end is

(Q)= m C_p ΔT
The quantity of heat available with hot slab coming out of roughing Mill
(Q) = m x Cp (t_1 – t_2)
= 15,000 X 0.483 (1050 – 30) **= 73,89,900 kJ**
Hence, 7389900 (-) 242892
= 15,000 X 0.483 (T_h – 30), **T_h = 986** ℃

Temperature available in the transfer bar at tail end
Hence, 7389900 (-) 357591
= 15,000 X 0.483 (T_t – 30), **T_t = 970** ℃

VII. Result Abstract

	*Heat loss due to **Radiation***	*Heat loss due to **Convection***	*Temp of Head End ($T_{head\ end}$)*	*Temp of Tail End ($T_{tail\ end}$)*	*Temp variation along the Length of Transfer bar*
Transfer Bar without Thermal shield	16964 KW	657 KW	962 °C	921 °C	41 °C
Transfer Bar with Thermal shield	4860 KW	119 KW	986 °C	970 °C	16 °C
Heat / Temp GAIN by placing Thermal shield	**12104 KW**	**538 KW**	**24** °C	**49** °C	**25** °C

From the above table, it could be seen that by introducing the Thermal shield

- *The radiation heat transfer from the Transfer bar reduces to **one third.***
- *The head-to-tail temperature variation along the length of a transfer bar got reduced to about **one third.***

VIII. Conclusion

This study is an attempt to reduce the heat loss taking place during the rolling process in Hot Rolling Mill (HRM) of a Steel Plant. Radiation heat transfer between two surfaces can be reduced greatly by inserting a thin, (low-emissivity) sheet of material between the two surfaces. Hence, it is proposed to cover the transfer roller table between rough & Steckel mill with THERMAL SHIELDS to minimize temperature loss of hot metal while it is conveyed from rougher to finishing mill and to decrease the temperature difference of head and tail end of hot metal on entering the finishing train. Furthermore, this technique has an environment impact such as reduction in fuel cost, reduced energy consumption and less emission in the furnace provided before & after the finishing Steckel mill.

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