BEHAVIOURAL STUDY OF JET IMPINGEMENT ON A STEEL ROLLED PLATE

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Abstract: One of the challenging problems in the steel rolling industry is the distribution of the heat flux across the geometry of the rolled plate under the cooling effect of water jet. Thus, the present work focuses on the heat transfer phenomenon of the steel rolled plate. The results obtained by the simulation studies indicate that wherein the nozzle of the jet is inclined at an angle more heat flux can be generated but the variation of the microstructure is not uniform across the width due to the impingement angle. Thus, maximum turbulence is observed at 45^0 jet angle. The results also indicated that the heat transfer coefficients are nonlinear functions of surface temperature. At the stagnation point, the surface temperature and heat transfer coefficient are not effected by the temperature of the cooling medium i.e., impingement of jet of water.

***Index Terms* – heat transfer, impingement, heat transfer coefficient, turbulence**

I. INTRODUCTION

The flow configuration can be studied for various industrial applications that require cooling by understanding the behavior of heat transfer caused due to the jet impingement on the surface. There is a growing demand to understand the heat fluxes from and/ or onto the surfaces which are subjected to high temperature. The focus of this paper is on jet impingement on steel rolled plate for the impinging jet normal to the plate and at an angle of the 45^0 to the plate. The rate of heat transfer also depends on the time of exposure of the plate to the water jet and it can be controlled using the roller speed etc.

Neil, et al.,[1,2] have studied the behavior about the numerical simulation techniques for impinging jet devices using various models like Reynolds stress model, k-«, k-v, turbulence models etc. Their study was to make a judgment about the model stability. Behina, et al., [3] have developed a numerical simulation for the jet impingement problem taking into consideration the jet impingement configuration. Yuling, et al., [4] presented the simulation results for a flat plate that is impinged by the semi-confined single turbulent jet. The results of simulation were in close agreement with that obtained for experimental results for large nozzle to target spacing. Anupam et al., [5,6] carried out review studies on the turbulent jet impingement and the heat transfer related to it. They also studied about the impact and effect of slot jet impingement using the techniques of LES and RANS.

Shankar, et al., [7] have determined the empirical relations for the heat transfer coefficient for the multi swirl impingement jets as the turbulence effect and the heat transfer rates are very high in this condition. Molana, et al., [8] studied the application of nanofluids for the liquid impingement jets so as to have more heat transfer. Michael, et al., [9] have studied the influence of the round gas jet on the flat plate/ wall under the effect of the turbulence intensity variation due to different Reynolds Number considered and jet configurations.

Ortega [10] had developed correlations for the heat transfer from a wall under the effect of the impinging swirling jet. The correlations were developed based on the CFD studies of the process. Marzec, et al., [11] have carried out the CFD analysis using CFX code to determine the effect of the different geometries of the nozzles utilized for impingement cooling. For the simulation studies CFX – SST turbulence model has been considered by modeling the problem that the flat surface is cooled using six impinging jets. Alenezi, et al., [12] have presented the correlation between the experimental and numerical results for the different jet configurations and conditions.

The studies by the various researchers focused on the jet profile, jet to plate distance and the amount of the heat transfer etc but they did not focus on the influence of these parameters on the plate that is being cooled. Thus, the present work focuses on the impact on the jet impingement on the steel rolled plate and the distribution of the heat flux and temperature in the rolled plate due to the impinging jet. There is lot of requirement and scope for study of the cooling behavior of the rolled steel strips in industrial applications as it has a direct impact on the phase transformation of the material. As cooling is carried out using the impinging jet there would be drastic changes in the mechanical properties of the material considered as under the influence of temperature, the micro structure varies .

II. METHODOLOGY

In a rolling process, the steel strip is subjected to very high temperatures in the range of 800-1000^{0}C and thereby it is cooled using the impinging water jets. When the water jet is impinged on the flat steel rolled plate then different modes of heat transfer get involved. The various modes of heat transfer are external and internal conduction, air convection, stagnation forced convection, radiation and forced boiling convection and most importantly the latent heat that is generated due to the material phase transformation. For a controlled cooling of the steel rolled strips, it is important to determine the heat transfer coefficient/ heat flux and jet impingement configuration. The present paper focuses on the heat transfer phenomena of the hot plate subject to the different jet configurations and heat flow rates.

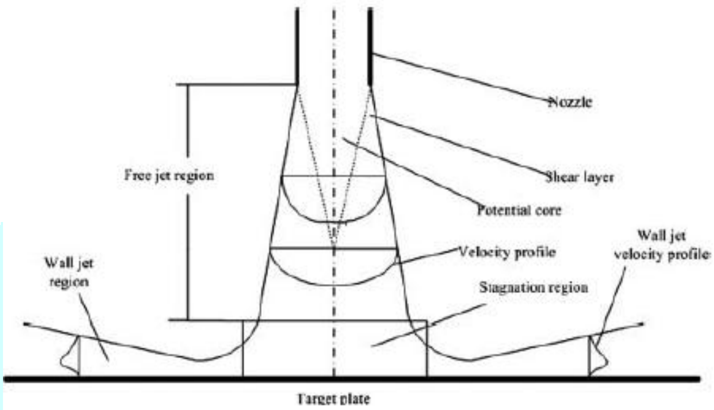

Figure 1: The various regions of impinging jet

The three important regions of jet impingement are the potential core, free jet region and stagnation regions as indicated in the figure 1. The free jet region has the vortices and they grow in the downstream direction. As these vortices entrain large quantities of the surrounding fluid, there is a drop in axial flow velocity of the impinging jet. But the core part of the free jet region is not affected and it maintains a constant velocity. Potential core is the irrotational part of the jet. As the shear layer spreads to the core of the jet the centerline velocity gets decayed along with the diminishing potential core. Thus, the jet velocity can be described as Gaussian Profile. When the jet attains the Gaussian profile it is considered to be fully developed single impinging jet. As the jet hits the flat plate the direction of impact changes into the transverse direction and thereby the axial velocity is lost and there is a sudden increase in the static pressure and this is described as the stagnation region and is the most complex region of the jet. In the impinging jets the stagnation region usually influenced by the high normal and shear stresses.

The various factors that have a substantial influence on the impinging jets are the nozzle to the plate spacing, the nozzle cross-section, nozzle exit conditions, Reynolds number, type of confinement – fully confine, semi confined etc., vortex dynamics. The present work focuses on the temperature distribution and heat flux in the steel rolled plate of 300 mm x 300 mm x 20 mm to a temperature of 1050^{0}C temperature. The rolled steel plate is cooled using the impinging jet normal to the plate and at an angle of 45^0 and with a varying distance between the jet to the plate. Thus, a steel hot rolled plate has been considered for analysis.

III. RESULTS AND DISCUSSIONS

The impinging jet and the plate distance are considered as parameters and the temperature distribution and heat flux distribution has been studied for two different configurations of the impinging jet.

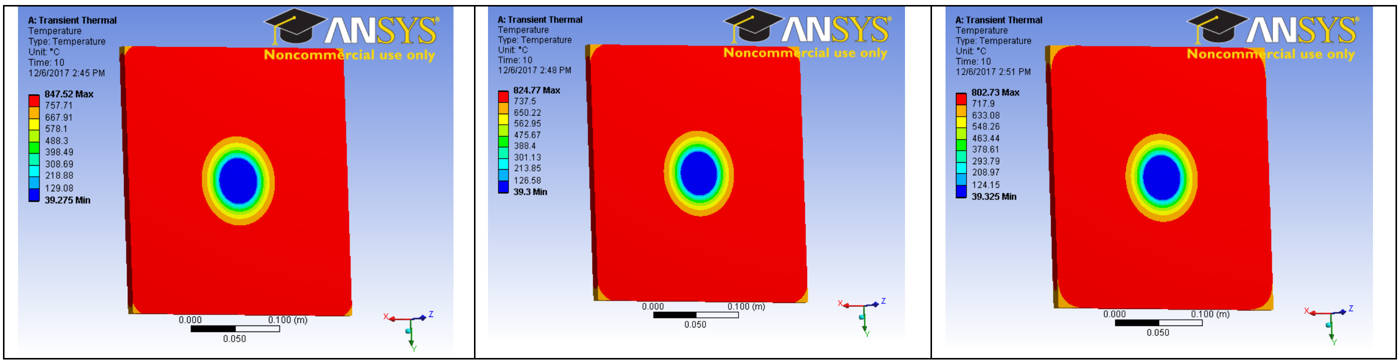

Figure 2: Temperature distribution in the steel rolled plate for 10 seconds with normal impinging jet

The jet to plate distance is represented by the parameter (Z) and its magnitude is varied as 2/4/6, figure 2 represents the temperature distribution in the hot rolled steel plate when it is subjected to normal impinging jet. There is a temperature variation from 847.52 to 802.73^0 C. As the distance is increased there is more temperature drop in 10 seconds as the surface area of the impinging jet is increasing.

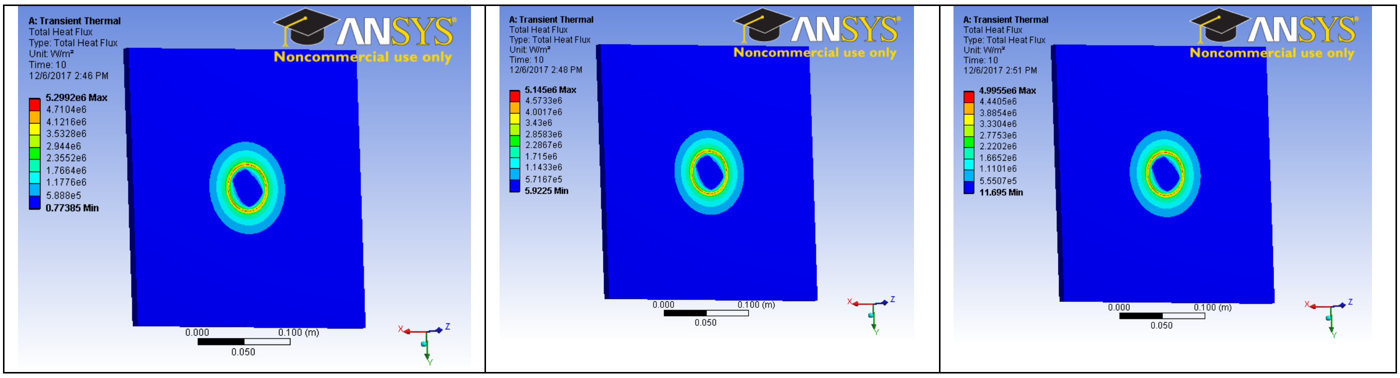

Figure 3: Heat flux distribution distribution in the steel rolled plate for 10 seconds with normal impinging jet

Figure 3 represents the heat flux distribution with a normal impinging jet with varying nozzle to plate distance, which varies from 5.29 W/m^2 to 4.49 W/m^2. As the nozzle to plate distance increases, the stagnation region increase but the amount of the heat flux decreases due to the time constraint of 10 seconds.

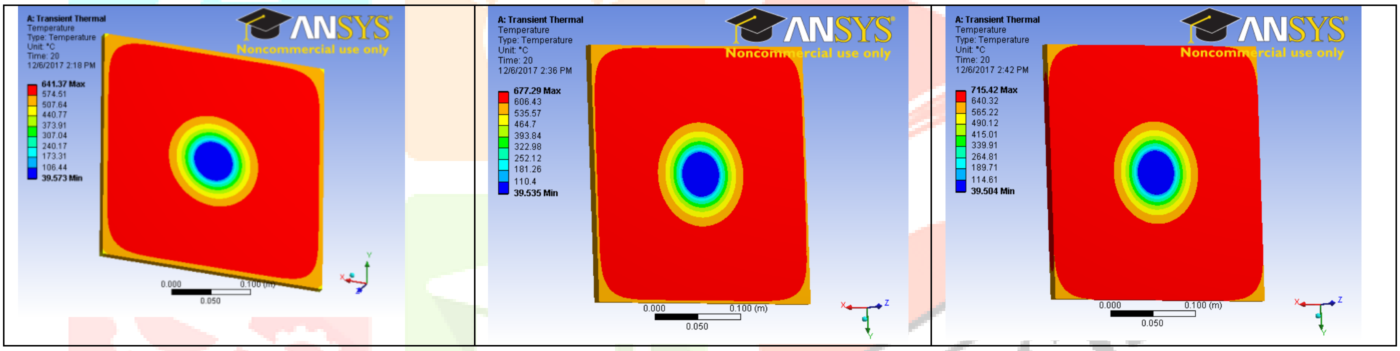

Figure 4: Temperature distribution in the steel rolled plate for 20 seconds with normal impinging jet

Figure 4 represents the temperature distribution of the steel rolled plate for 20 seconds and its magnitude varies from 641.37^0 C to 715.42^{0}C.

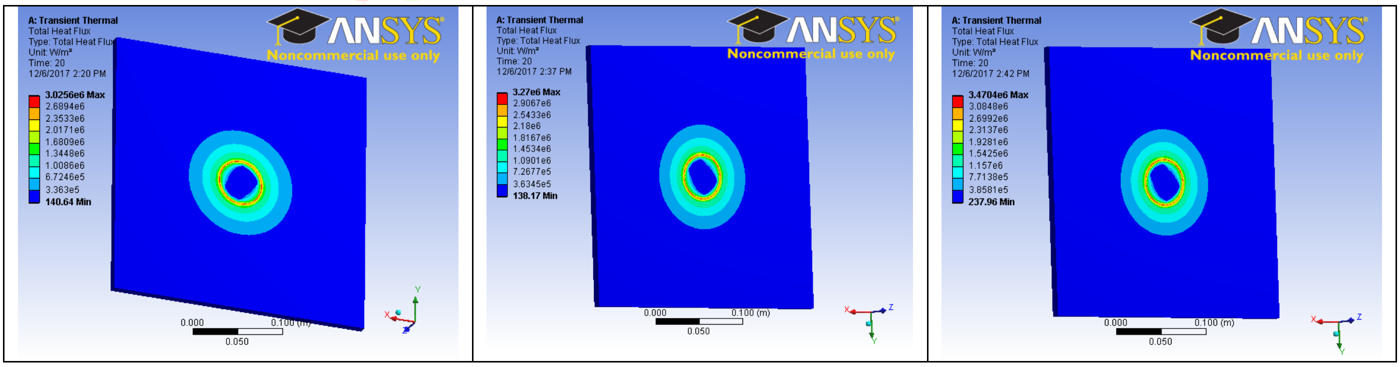

Figure 5: Heat flux distribution distribution in the steel rolled plate for 20 seconds with normal impinging jet

Figure 5 represents the heat flux distribution of the steel rolled plate for 20 seconds and its magnitude varies from 3.02 W/m^2 to 3.47 W/m^2.

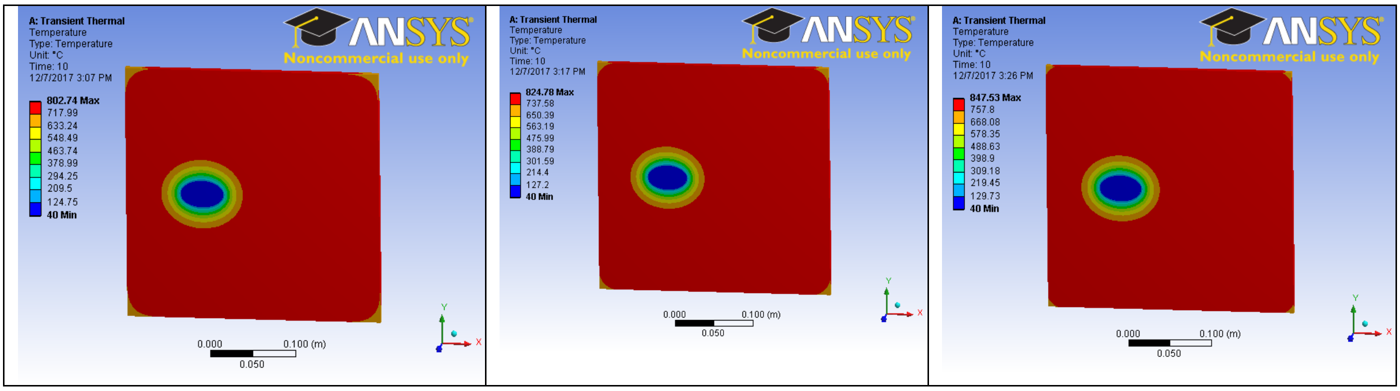

Figure 6: Temperature distribution in the steel rolled plate for 10 seconds with inclined impinging jet

Figure 6 represents the temperature distribution in the hot rolled steel plate when it is subjected to inclined impinging jet. There is a temperature variation from 802.70 to 847^0 C. As it is an inclined jet, there is more temperature drop in 10 seconds as the surface area of the impinging jet is increasing.

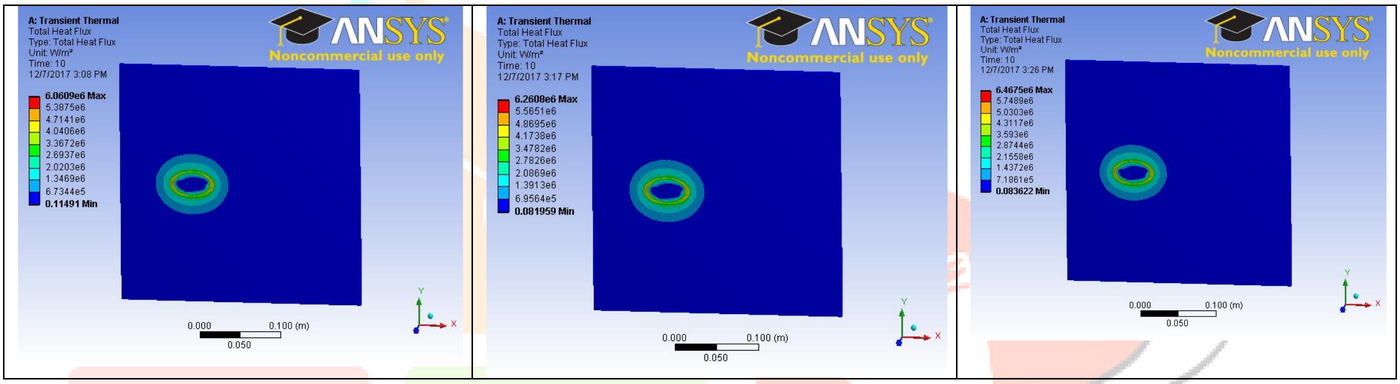

Figure 7: Heat flux distribution in the steel rolled plate for 10 seconds with inclined impinging jet

Figure 7 represents the heat flux distribution with a inclined impinging jet with varying nozzle to plate distance, which varies from 6.06 W/m^2 to 6.46 W/m^2. As the nozzle to plate distance increases, the stagnation region increase and also the amount of the heat flux is increasing in case of the inclined impinging jet.

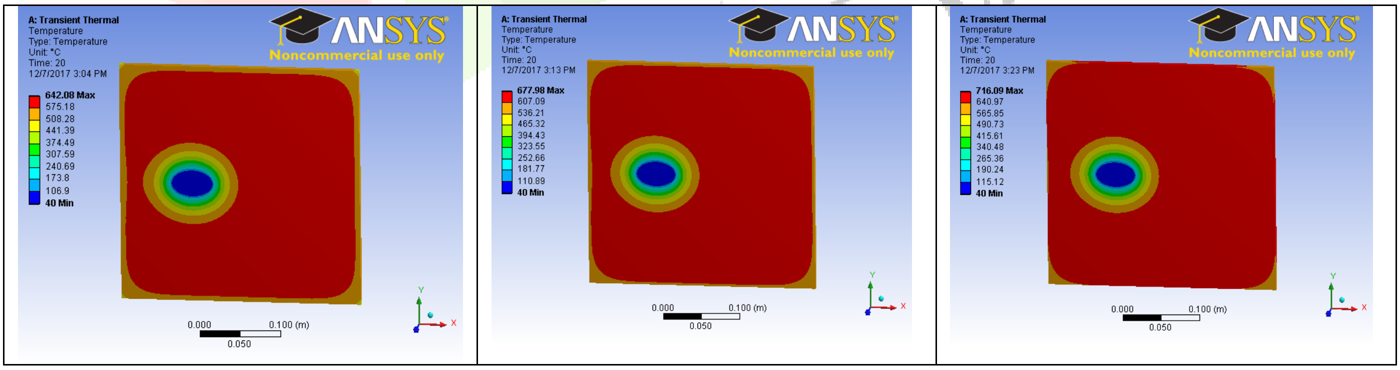

Figure 8: Temperature distribution in the steel rolled plate for 20 seconds with inclined impinging jet

Figure 8 represents the temperature distribution in the hot rolled steel plate when it is subjected to inclined impinging jet for a time span of 20 seconds. There is a temperature variation from 642.08^0C to 716^0 C. As the heat transfer coefficient for the inclined jet is varying with the varying distance the impact of temperature drop is different compared to the normal impinging jet.

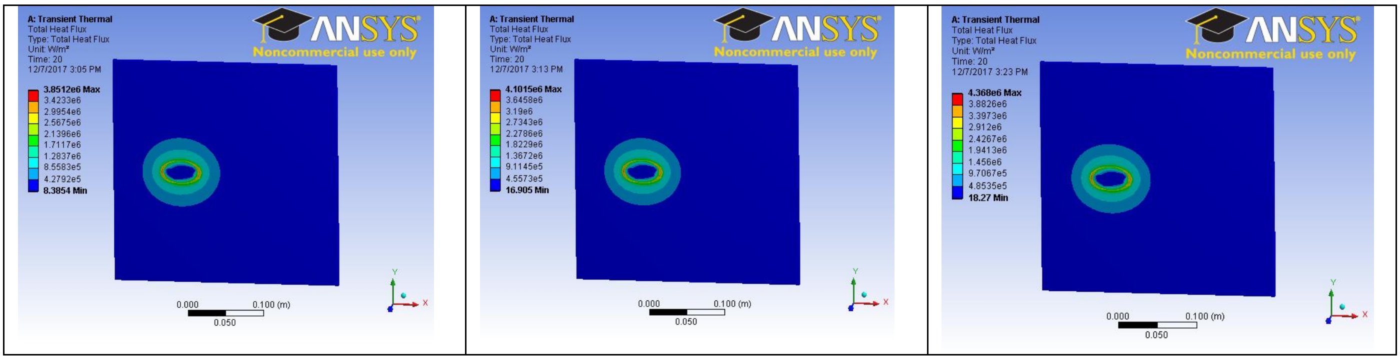

Figure 9: Heat flux distribution in the steel rolled plate for 20 seconds with inclined impinging jet

Figure 9 represents the heat flux distribution with a inclined impinging jet with varying nozzle to plate distance, which varies from 3.85 W/m^2 to 4.36 W/m^2 for a time period of 20 seconds. In inclined impinging jet, the heat flux is more when the distance between impinging jet and hot rolled steel plate is more.

IV. CONCLUSIONS

A hot rolled steel plate of a temperature 1050^{0}C subjected to a water impinging jet having configurations of normal to the plate and inclined to the plate indicated that there would be more temperature drop and heat flux in case of the inclined jet due to the increase in the contact surface area of the jet and thereby increase in the volume of the stagnation region. The simulation studies indicates that the uniformity in the stagnation region by adjusting the jet configurations so as to avoid the vortex in the fluid flow will lead to more uniform microstructure in the rolled hot steel plate.

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