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A Review on Thermal Analysis of Hot Rolled Steel Plate to Minimized the Edge Wave Effect

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Abstract

The effect of an increment of water flow is translated into an increment of the thermal drop in the steel plate, but more clearly in center of the steel plate than in the edges. This can be explained by a non-uniform water distribution having a higher flow in the edges probably due to the water coming from in the center to the drainers. Residual stress is then generated by non-uniform cooling, which influences the shape of the plates. The shape of high-strength steel plates is more difficult to correct after cooling to room temperature than that of low-strength steels. Therefore, reducing the thermal buckling and stress of steel plates on the run-out table (ROT) is important.

Keywords: *Thermal Analysis; ROT; Wave Edge; Rolling.*

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1. Introduction

Due to economic globalization, industry is facing severe competitors. To get success in this environment, the industry must significantly improve productivity and quality and reduce defect less product and waste during production. In addition to economic consideration requirement also strongly derive steel industry toward that direction therefore, there is an urgent need from steel industry for effective process quality control. Since the rolling operation is often the last process step of raw materials of several products, hence the scrap from defects at rolling stage is very costly and the quality control of rolling process has a vital role. The research has been carried out at Plate mill of Bhilai Steel Plant, SAIL to minimize the defects in hot rolling plate.

Rolling is a forming operation where the metal is compressed between two rotating rolls for reducing its cross-sectional area. The reduction that can be achieved with a given set of rolls which is called rolling stand. Two types of rolling like hot rolling and cold rolling of the metals are affecting the process of forming. In this work the various parameters which effect the hot rolling process are being included and analysed. [4]

Figure 1. Edge Wave Defect in Steel Plate

2. Literature Review

Zengshuai et al (2018) presented a paper titled as “Reduction of Residual Stress for High-Strength Low-Alloy Steel Strip Based on Finite Element Analysis”. This study is applying a three-dimensional FE model of a high-strength low-alloy steel strip on the ROT to simulate the coupled processes of thermal, phase transformation, and stress. It was named as basic model. Several experiments and tests were performed to verify the precision of the Basic Model. Several FE models were built based on the Basic Model to quantitatively analyze the effect of the four methods. Several conclusions can be summed up from this research as follows:

- The phase transformation products in the strip during cooling are ferrite and bainite on the edge but only ferrite on the central section. The different cooling rates and initial temperatures cause these differences.
- The distribution of the residual stress on the transverse of the steel strip after cooling is compressive stress on the edge and tension on the central section. Thus, the flatness of the steel strip tends to develop edge waviness according to shape theory.

The effect of the four methods on reducing residual stress ranks follows the order (descending): reducing the ITTD of the steel strip, the SC, the EM, and the PC. [26]

Sharma and Suri (2017) presented a paper titled as “Implementation of Quality Control Tools and Techniques in Manufacturing Industry for Process Improvement”. This study is to apply Quality control tools in production process to reducing the rejection and rework by identifying where highest rejection occur at and to go give suggestions for improvement. This study is conducted from one of the Leading Manufacturing industries in Noida which manufactures Low voltage Panel board products. It has been founded that the company has many problems especially there is highly rejection and rework in the production processing lines. There is a various process parameter such as Punching, Bending, welding, grinding, Painting, Assembly and wiring process etc. which have influence of the quality of final products have to be controlled in order to reduce the wastage and also there have been observed a need of improvement by using the quality control tools. [10]

Deepak and Dhingra (2016) presented a paper titled as "Application of quality control tools in a bicycle industry". This study is aimed toward reducing the rejection of Bicycle rims by application of Quality Control (QC) Tools. A case study has been conducted in a bicycle industry in Ludhiana to improve the quality of the bicycle rims. The Quality tools such as Pareto chart, Fishbone diagram m have been applied to improve the quality of the products. It has been found that monthly defects were reduced to greater extent. The various process parameters such as heating voltage, temperature of heated water, time of chemical coating processes, chemical composition of the material and quality of heated water etc. which have influence of the quality of final product have to be controlled in order to reduce the wastage. [4]

Hrabovský et al (2016) presented a paper titled as **"**Experimental and numerical study of Hot-Steel-Plate flatness". The analyses presented in this paper focused on the study of non-homogeneous cooling and its impact on the deformation of a steel plate. Several numerical models of steel plates were prepared. The first model computed time-dependent temperature fields. Plant measurements were simulated using this model. The results obtained from the simulation agree with data obtained during the plant measurements. The second numerical model focused on the cooling process of the steel plate and the impact of thermal fields on the final deformations of the steel plate. The FE simulation of the cooling process showed the impact of the non-homogeneity in the thermal field on the final deformations. The simulations confirmed that the plate is bent towards the side with the higher cooling intensity in the initial cooling stage; however, in the later stages, the plate is bent towards the opposite side, with the lower cooling intensity. [12]

Sheth et al (2015) presented a paper titled as "Investigation, Analysis of Casting Defect By Using Statistical Quality Control Tools". This paper represents analyses and investigation of casting defects and identification of remedial measures carried out at specific industry. Diagnostic study carried out on overall process of casting. Casting's products revealed that the contribution of the five prominent defects in casting rejections were found and they are sand drop, blow hole, fin, and rough surface and cold shut. It was noticed that these defects were frequently occurring at different locations. Systematic analyses were carried out to understand the reasons for defects occurrence and suitable remedial measures were identified and implementation of lean six sigma up to some extend and generating feedback system between two industries. [8]

Patel et al (2014) presented a paper titled as "Application of Quality Control Tools in Taper Shank Drills Manufacturing Industry". This Paper describes the application of seven Quality tools in Taper Shank drill Industry. Quality tools are used to monitor the overall Process and continuous process improvement. These basic tools applied on Company data and analyzed this data and find the Root-causes. On the basis of root causes, going to take action plan for further improvement. [17]

Cho et al (2014) presented a paper titled as "Finite Element Investigation for Edge Wave Prediction in Hot Rolled Steel during Run Out Table Cooling"**.** This study is focused on for predicting edge wave behavior of hot rolled steel during ROT cooling was investigated using a three-dimensional FE model. The heat transfer, phase transformation, and deformation were considered simultaneously during the computation, and the edge wave of the hot rolled steel is reproduced successfully based on the proper thermo mechanical boundary conditions. The computed results demonstrated that the strain gradient due to the temperature difference between the edge and center regions could cause the edge wave of the final product. The maximum amplitude of the edge wave was used as a parameter of the degree of the edge wave. The simulated results also showed that both increasing the width of the edge mask and removing the checkers could reduce the edge wave of the final product. Finally, the measured temperatures at the CT agreed fairly well with the predicted data, and these results show sufficient possibilities for the proposed analysis method, which can effectively predict the changes of thermo-mechanical behavior during the ROT cooling by using the developed numerical model. [11]

Jadhav et al (2013) presented a paper titled as "Investigation and analysis of cold shut casting defect and defect reduction by using 7 quality Control tools". This case study represents procedure to analyses and minimizes casting defect Cold shut-in automobile cylinder block of grey cast iron Grade FG150. Gaiting systems are not always responsible for the defect occurrence; this paper represents the defect reduction by controlling alloy composition and pouring temperature. The seven quality control methodology is used to analyses and reduce defects which includes check sheet, pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart. [18]

Rai et al (2013) presented a paper titled as "Causes & Presentation of Defects (Burr) In Sheet Metal Component". In this paper Burr formation is common sheet metal defect and Burr control / deburring is an important issue for industrialist and engineers. It is produced in all shearing & cutting operations. In sheet metal parts burr is usual but after a specified limit it takes a form of defect. This leads to rework and quality problem of part. So controlling this defect is the issue of quality as well so a study of all relevant factors is done in this paper, individually. This paper describes that what are the possible causes & how can we prevent it. [16].

Suebsomran and Butdee (2013) presented a paper titled as **"**Cooling process on a run-out table by the simulation method". This study aims to determine the effective cooling parameters for the run-out table (ROT) of strip steel in a hot rolling process. Two-dimensional transient heat conduction is developed, including the external force convection and heat source due to translational motion. The strip velocity, cooling water temperature and external fluid velocity are chosen to study the influent parameters during the cooling process. To determine 2-dimensional transient heat conduction in the cooling process of strip steel, numerical methods are applied to solve for the temperature of the strip steel with appropriate boundary conditions. The backward difference formula (BDF) applies to the discretization of a partial differentiation equation (PDE). The parallel sparse direct linear solver (PARDISO) is applied to the computation in the form of a linear algebraic equation built with the COMSOL Multiphysics software for the heat transfer module. The simulation studies are divided into 12 case studies with three variations subjected to cooling conditions at the ROT. From the results of the simulation study, appropriate parameters to determine the temperature required for strip steel are achieved. [3]

Wang et al (2013) presented a paper titled as “FEM analysis for residual stress prediction in hot rolled steel strip during the run-out table cooling”. This study is applying a thermal, microstructural and mechanical coupling analysis model for predicting flatness change of steel strip during the run-out table cooling process was established using ABAQUS Finite Element Software. In this model, Esaka phase transformation kinetics model was employed to calculate the phase transformation and coupled with temperature calculation by means of the user subroutine program HETVAL. An elasto-plasticity constitutive model of the material, in which conventional elastic and plastic strains, thermal strain, phase transformation strain and transformation induced plastic strain were taken into account, was derived and realized using the user subroutine program UMAT. The conclusion that the flatness of the steel strip will develop to edge wave defect under the functions of the different thermal and microstructural behaviors across strip width direction during the run-out table cooling procedure was acquired through the analysis results of this model. The calculation results of this analysis model agree with the actual measurements and observation; therefore, this model has a high accuracy. To better control the flatness quality of hot rolled steel strip, the shape compensation control strategy of slight center wave rolling is proposed based on the analysis result. This control strategy has been verified by actual measurements and applied in actual production. [25].

Wang et al (2013) presented a paper titled as “Finite element analyses of TMCP steel plates with consideration of edge masking”. Complex thermal stress and distortion are inevitably generated in TMCP (thermomechanical controlled process) steel plates. The excessive distortion due to uneven cooling may be detrimental to the integrity of TMCP steel plates. To improvement the uniformity of TMCP steel plates, they are partially masked near the edge of the plate in the water spraying cooling process. In order to assist process engineers to select appropriate edge masking amounts, the effects of the edge masking amounts on thermal stress and distortion of TMCP steel plates are investigated by finite element analyses. Scheil’s additivity rule and Johnson-Mehl-Avrami-Kolmogorov (JMAK) model are considered in the phase transformation model of the thermo-elasto-plastic finite element program. The effects of edge masking on the distortion of the TMCP plates are presented. [6]

Chandna and Chandra (2009) presented a paper titled as “Quality Tools to Reduce Crankshaft Forging Defects”. In this work the forging analysis of six-cylinder crankshaft produced by hot forging with the help of quality tools is being made. The analysis shows that more than 80% of rejection and rework are due to forging defects like overlap, underfilling, pitting, foreign body and shop scrap. Corrective measures are being suggested to overcome the forging defects of the 697 integral counter weight crankshafts. Finally, few remedial measures and suggestions have been provided for the existing crankshaft production line in the forging shop and controlling vital few forging defects will reduce the present rejection rate from 2.43% to 0.21% and rework from 6.63% to 2.15%. [15]

Zhou et al (2007) presented a paper titled as “Numerical analysis of the flatness of thin, rolled steel strip on the runout table”. This study to following can be concluded: A finite element analysis of the flatness of thin, rolled steel strip is presented. The occurrence of edge-wave and center-buckle is predicted numerically by solving the eigenvalue problem. The form of buckles is calculated using a non-linear load–displacement analysis. Buckling changes from the center to the edge as the maximum difference in temperature between the edge and centre increases; correspondingly, the amplitude increases and the wavelength decreases. Because uniform applied tension then decreases the compressive stress at the edge and increases the stress in the centre, a centre-buckled strip is flattened by applied tension, but edge-buckling becomes more severe and applied tension may change the type of buckling from the centre to the edge. Crowned strip resists buckling whereas a concave profile tends to promote it. The effects of the magnitude of the crown or concavity on centre-buckling of the strip are more significant than on edge-buckling. [27]

Peregrina et al (2006) presented a paper titled as "Hot strip flatness optimisation by means of edge masking in the ROT". It can be concluded that: The control of temperature distribution across the strip is essential for the hot strip flatness improvement. Hot strips of Arcelor in Avilès may display wavy edge defects that are generated after the finisher and are attributed to residual stresses introduced by the accelerated cooling on the runout- table. A first approach has established that the thermal drop on the run-out-table has a significant effect on flatness, at the edges in particular. Among several systems that may control temperature at the edges, the edge masking technology has been selected, considering the previous implementation on CSP mills. Wavy edges are considerably removed or even suppressed on the operator side, while they are reduced but not eliminated on the drive side. [20]

3. Conclusion

During production of plates in plate mill is facing rejection problem for plate having grade of IS2062-250BR. The major rejection is due to the edge wave defect which contributes up to1.34% from 4.10% of total rejection production. Hot rolled plates display wavy edge defects that are generated after the finishing stand and are attributed to residual stresses introduced by the accelerated cooling on run out table. Accelerated cooling technology has been widely applied in recent years. Two modes can be applied to achieve high cooling rate by increasing the density of cooling nozzles or by increasing cooling water pressure. With rapid cooling, the temperature of the plates quickly drops below the phase transformation temperature, thereby inducing early phase transformation. This condition decreases the size of austenite grains, whereas the ferrite grains are refined despite the little consumption of alloying element. Furthermore, cooling the plate evenly is difficult because of the large flow of cooling water.

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