Influence of Metal Temperature on Strength of Rolled Steel Product

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Abstract—Rolling is extensively used metal forming process. Almost 90% of cast iron or steel products pass through rolling process at least once in its life cycle. Rolling products are most extensively used in daily life. Use of these products can be seen in bridges, towers, leaf springs, boilers, constructional structural parts and also in daily life products like knives pipes etc. In today's era, quality of products is one of most important factor considered for its use. Quality of a product can either be controlled or improved by changing in composition or by using heat treatment processes. In rolling products composition is not only the factor which improve the quality of product but temperature plays a vital role in maintaining and improving quality. By changing temperature of rolling we can change grain structure and its mechanical properties without changing its composition.

Keywords: Rolling, mechanical properties, steel, microstructure.

I. INTRODUCTION

Rolling is one of most widely used method of metal forming. Rolling is a metal forming process in which metal stock is passed through a pair of rolls. Rolling is classified according to the temperature of the metal rolled. By metal rolling we can produce strips and plates. Widely Rolling can be described in to types, one is cold rolling and another one is hot rolling. In cold rolling process metal is rolled below its recrystallization temperature & in hot rolling the metal to be rolled is heated above recrystallization temperature before rolling. In hot rolling temperature is one of most important factor, it controls the kinetics of metallurgical variables such as strain, stress and micro-structural properties like surface finish. Temperature also leads to conversion of brittle stock (Billet) to soften raw material which is further operate under high pressure rolls. A billet is heated at very high temperature which may also be near to its melting point. Usually a billet is heated till its color changes to orange yellow. It flows in rolls as like dough in between a cookie roll. An 8-9 inches billet is converted in a flat with application of high pressure. The weight of rolls may be varying from few kilograms to 250 tones. A continuous rotation of rolls and flow of stock produces compression and frictional forces between metal stock and rolls. This rolling mill stands driven by motors upto 77,000 hp and produces sufficient force to change cross-sectional area of metal. Shape of final product is based on the contour shape on rolls. The thickness of final product is also depends upon gap between both rolls [1]. Basic principal of rolling is that stock passes between pair of rolls which are revolving at same speed but in opposite directions. The gap between these rolls is slightly less than the required thickness. Revolving motion produces friction between rolls and metal stock; also there is heavy load acting on stock at area of contact between rolls and stock. As the metal passes through these pairs of rolls the forces acting on metal results in change in cross-sectional area of stock. As shown in figure 1 (a & b) the thickness of metal reduces as it passes through the rolls and the width of metal increases. The cross-sectional area of final product is controlled by changing the gap distance between rolls and width is controlled by making constrain at exit face of rolls [2].

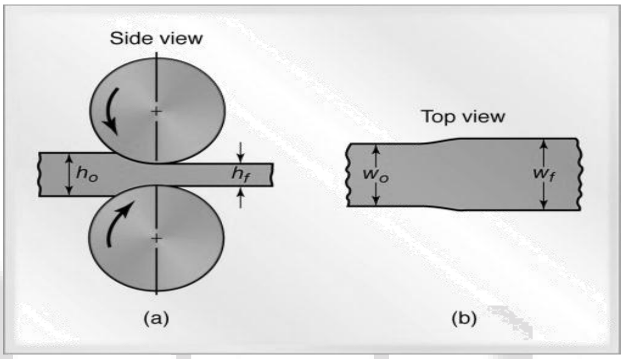

Fig. 1 (a) side view of metal passes though rolls (b) top view of metal stock

II. HISTORY OF ROLLING

Invention of rolling is attributed to Leonardo da Vinci. It was introduced as passing flat bars between iron rolls to make iron plates by reducing their size with the application of force by both the rolls. Such rolls with grooves were also being used to produce iron rods, these were called as slitters. This technique was further used in making tin plates.

But modern Rolling was introduced to steel production in 1783 by Henry Cort, who successfully improved on earlier primitive attempts to use this technique. Since Cort's early rolling mill, which used grooved rollers, there has been a continuous development of the process and of the size of mills. Modern mills have as many as four sets of rollers, one above the other, and steel is rolled in a continuous process through one set, into another, and then back again, until the desired shape is achieved. Semi-finishing mills roll the steel into rectangular shapes to be further refined; finishing mills produce steel ready for use in manufacturing. The first rail rolling mill was established by John Birkenshaw in 1820 where he produced fish bellied wrought iron rails in lengths of 15 to 18 feet.

III. LITERATURE REVIEW

Research of hot rolling is very wide. Numbers of research papers are studied, which have given lot of information and data regarding the rolling parameters which plays vital role in efficient hot rolling process. Brief description of previously done studies in the area of hot rolling are discussed below as:

Herman *Et Al.* (1997) Author aims to **c**hange different parameters of hot rolling process to reduce damage in surface and microstructure of metal slab. Low carbon steel contains less than .05% of carbon. To increase the efficiency of rolling, metal should be rolled when it's soft or at austenite stage, so called ferritic hot rolling. Low carbon steel is suitable for thin gauge strip with strained Microstructure at 600 degree Celsius. Such parameters used to change to improve surface quality & microstructures are:
(a) Temperature at which cooling of metal strip done.
(b) Addition of another material in low carbon steel to improve its quality.

By changing temperature during reheating, roughing and finishing temperature changes surface and microstructure of low carbon steel strip. Energy saving can be derived by lowering the reheat temperature. Less surface defects generally induced by the use of a low Mn content or high temperature rolling stage at the edger mill. Better strip flatness control by rolling and cooling a transformed and homogeneous ferritic microstructure. Cost reduces as the as in terms of energy saving, work roll wear etc [3].

Auzinger *et al.* (1997) The system of VOEST-ALPINE lndustrieanlagenbau GmbH (VAl) for computer - Aided Quality Prediction and Control (CAQPIC) allows accurate on-line prediction of the quality parameters of hot rolled strip. It was developed in close cooperation with one of Europe's best steel producers VOEST-ALPINE STAHL LINZ (VASL) and is in the implementation stage at the Hot Strip Mill (HSM) of VASL. In this study a computer network is used to control the parameters like temperature and size etc. It is done controlling reheating furnace, cooling system, finishing mill by connecting all systems to a server with networking. A pre-determined data regarding temperature, strength, elongation are already stored in server which matches the outputs with saved data [4].

Serajzadeh *et al.* (2002) In this paper author represents a mathematical model to for predicting the temperature distribution and austenite microstructural changes during hot rolling of steel. The mathematical model is based upon finite element method for evaluating temperature distribution and also determines the strain field. Results given by this prediction model is the temperature distribution is more inhomogeneous in early stage of deformation passes and in final stages, temperature becomes uniform though the thickness of rolling material, smaller cross-section of bar and high speed of rolling [5].

Sheikh (2009) In this paper author performed thermal analysis of hot rolled strip. Since temperature is most governing parameter for behavior of steel during hot rolling. A mathematical model is made using FEM and FDM codes. a mathematical model is presented which is capable of predicting the temperature distribution and the roll force of hot rolling process. Therefore, the Avitzur's approach was joined with finite element analysis and was employed in simulation of hot rolling process of steels. Petrov–Galerkin scheme was utilized to stabilize the numerical oscillations of finite element analysis. The predictions were found to be in good agreement with published results showing the reliability of the employed model. Also, this model is a simple approach in comparison with other approaches such as thermo-viscoplastic finite element for prediction temperature distribution of hot rolling process [6].

IV. OBJECTIVES OF STUDY

After studying the above literature, it can be concluded that a large amount of work has been done on rolling process using various combinations of input parameters. Some of them have found effects of these parameters on hardness, size, surface finish; some related these parameters with rolling forces and cooling effect. Some researchers used different types of compositions of material to improve properties of finished product. Many studies used FEM, mathematical models, stimulation models, some computer network systems etc.

The development in rolling process is continuous from the day one rolling starts. In some studies new improved methods are suggested for rolling and many other methods to improve mechanical properties are studied. Chemical composition and microstructure of metal are discussed to increase the strength of product as well as surface finish in various studies.

Depending upon the literature survey presented in this chapter, following objectives are drawn to carry out the research work:

1) To study the effect of temperature on mechanical properties such as hardness of hot rolled steel flat.
2) To find the optimum range of temperature which provides better mechanical properties of the hot rolled product.

V. EXPERIMENTATION

Experiments are conducted on steel flats by selecting the temperature as input parameter. The working range of the input parameter is selected by repeating the trials. Different specimens are prepared for testing of different mechanical properties like hardness, toughness and tensile strength of steel flat by hot rolling process.

VI. METHODOLOGY

Methodology phase consists of planning and conducting the experimental trails on the basis of literature survey to select the parameters, input and output and experimental setup which are as follows:

1) Samples are prepared by changing temperature at initial (furnace) end.
2) Each sample is passed through rolling process to produce final product to be tested.
3) Specimen is prepared for testing.
4) Tensile Strength specimen is tested to conduct final outcome results.

The samples prepared are of same configuration but are rolled at different temperature. There specimen are not hardened after rolling but are allowed to cool down at room temperature. Initial temperature is the temperature of metal before rolling, when it is taken out of furnace and final temperature is when it passes through rolls and cool down by water spray effect. This water jet spray leads to drop the temperature of metal stock from 400°C-450°C. The variation in initial and final temperature of each specimen is shown in table. These temperature ranges of samples are selected on the basis of re-crystallization temperature of medium-carbon steel. The lowest temperature suitable for rolling medium carbon steel is 500°C and highest temperature at which furnace can be operated for heating steel is 1350°C which gives initial temperature at exit of furnace 1000°C. To perform testing 12 samples are taken at different temperatures initial temperature starting from 530°C each with difference of 40°C.

Sr. No.	Initial temperature (°C)	Final temperature (°C)
1	530	130
2	570	175
3	610	215
4	650	255
5	690	300
6	730	335
7	770	380
8	810	420
9	850	450
10	890	495
11	930	530
12	970	595

Table 1: Variation in temperature for each sample

VII. TESTING

Tensile Strength - Strength is a measure of how well a material can resist deformation from its original shape. Typically, metals are specified for their tensile strength or their resistance to being pulled apart. Strength is measured in units of pressure, and is typically reported in units of ksi, or "thousands of pounds per square inch. Steel has a relatively great amount of tensile strength compared to other materials, such as concrete, which possess a great amount of compressive strength but little tensile strength. In general, the tensile strength of steel is equivalent to its compressive strength. That is, steel responds to stretching force in much the same way it responds to crushing force, although the possibility of shearing forces must be taken into account when steel is subjected to compression loads. The tensile behaviour and ultimate mechanical properties are very important characteristics of semi-crystalline polymers. These macroscopic properties are known to be closely dependent on the strain rate, thus an understanding of strain rate dependence of their deformation behaviour is important for encouraging their wide use in engineering and structural applications. Strain rate has a complicated and dramatic effect on materials deformation processes because the energy expended during plastic deformation is largely dissipated as heat. For performing strength test the specimen is prepared as dumbbell shaped for getting more precise readings. The specimen's shape is usually defined by the standard or specification being utilized, e.g., ASTM E8 or D638. Its shape is important to avoid break or fracture within the area being gripped. So, standards have been developed to specify the shape of the specimen to ensure that break will occur in the "gage length" (2 inches are frequently used) by reducing the cross sectional area or diameter of the specimen throughout the gage length. This has the effect of increasing the stress in the gage length since stress is inversely proportional to the cross sectional area under load.

Tensile Strength testing: The result of hardness testing by Universal testing machine is represents by table 2. The relation between temperature at final end i.e. after rolling and Strength of specimen is shown in figure 2. As the results shown in figure with increase in temperature the strength of product decreases.

Serial no.	Initial temperature (°C)	Final temperature (°C)	Tensile Strength (Mpa)
1	530	130	990
2	570	175	946
3	610	215	912
4	650	255	889
5	690	300	871
6	730	335	862
7	770	380	859
8	810	420	851
9	850	450	839
10	890	495	806
11	930	530	796
12	970	595	767

Table. 2: Result of Tensile Strength Testing

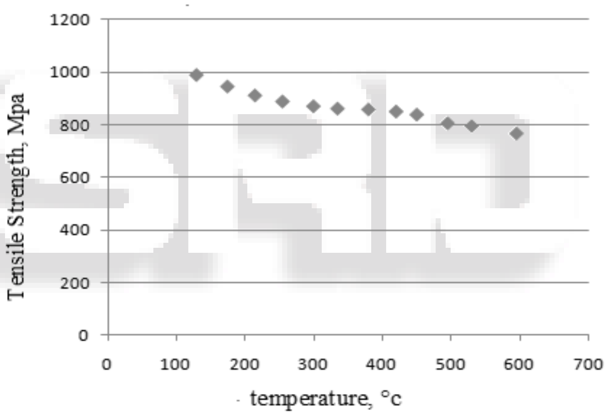

Fig. 2: Relationship between temperature and tensile strength of rolled material

As shown in figure 4.9, the tensile strength of given specimen decreases with increase in temperature. It falls proportionally with increase in temperature in first two readings i.e. at 130°C and 145°C. But in range between 150°C-200°C the trend changes and tensile strength vary less as compare to first two readings. In the between range of 300°C-400°C the variation in tensile strength is least as compared to all cases. When temperature goes higher from 400°C, the tensile strength again falls down. In previous studies we also found that by increase in temperature of rolling product, tensile strength decreases.

VIII. RESULTS

The influence of process factor such as temperature, on the mechanical properties of hot rolled steel flats in a conventional mill has been investigated. From the analyses of results obtained, it can be concluded that in hot rolling the type and extent of in-process cooling method and duration of each rolling cycle largely determine the finishing temperature. Conclusion drawn from present study is given below:

1) Tensile strength decreases, with decrease in temperature and there is least deviation in value of harness when temperature is between 300°C and 400°C, value of Tensile Strength of given specimen lies between 871Mpa and 851Mpa.
2) By investigating the effect of temperature on mechanical properties such as hardness & tensile strength, it is found that if temperature of stock before rolling is between 700°C-800°C and final temperature is in between 300°C-400°C, it will give an optimum value of hardness, impact strength and tensile strength. For same composition of metal within this range of temperature the deviation in these properties is very less. Therefore, it becomes easy improve mechanical properties of Medium-Carbon steel if its temperature is maintained within this optimum range.

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