Measurement of the Residual Stress in Hot Rolled Strip using Strain Gauge Method

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Abstract-Measurement of the surface residual stress in a flat hot rolled steel strip using strain gauge method is considered in this paper. Residual stresses arise in the flat strips when the shear cut and laser cut is applied. Bending, twisting, central buckled and edge waviness is the common defects occur during the cutting and uncoiling process. These defects arise due to the non-uniform elastic-plastic deformation, phase transformation occurring during cooling and coiling-uncoiling process. The residual stress analysis is very important because with early detection it is possible to prevent an object from failure. The goal of this paper is to measure the surface residual stress in flat hot rolled strip using strain gauge method. The residual stress was measured in the head and tail end of hot rolled strip considering as a critical part of the strip.

Keywords: Hot-rolled steel strip, Residual stress, Strain gauge.

1. INTRODUCTION

The hot rolling process is a process of making the steel plate, strip from the slab at high temperature. This whole process consists of heating, coiling-uncoiling and cooling. The hot rolled strip made from the hot rolling process is widely used in automotive, construction, pre-engineered building and lifting & excavation applications. Hot rolled strip is to be cut based on different application through laser cut or shear cut. During the cutting process, steel strip gets bent or twisted due to the presence of residual stress.

Residual stresses are the internal stresses which reside in the hot rolled strip during hot rolling process. Residual stresses arise in steel strip due to following aspects-

1. Non-uniform elastic-plastic deformation in the volume [1].
2. Stress relaxation phenomenon at high temperatures [2].
3. Phase transformation occurring during run-out table cooling process [3].
4. Cooling occurring in coiled strip [1].
5. Coiling-uncoiling of the hot rolled strip [3].

During the past decades many researchers have measured the residual stress experimentally predominantly using hole drilling technique. However, the drilling process invariably induces an additional stress, which affects the precision of the measurement results [4]. The edges correspond to the compressive residual stress and center corresponds toes the tensile residual stress inside the volume [1]. It has been concluded that mechanical loads, thermal loads and microstructure transformation are the main sources of the machining-induced residual stress [5]. The residual stress existing in the surface layer is an important aspect of the surface integrity that can influence the performances of the mechanical parts such as fatigue life [6] and corrosion resistance [7].

The surface stresses play a crucial role to cause the deformation of a steel sheet or plate. Therefore, the goal of this study is to measure the residual stress on the surface of the hot rolled strip. Numerical prediction of residual stresses become of practical importance when the laser cutting of the strips is applied [8]. Therefore, the head and tail end of the steel strip has been considered as the critical sections which corresponds to the higher amount of residual stress due to which these sections gets bent, edge waved, twisted and central buckled after cutting and uncoiling.

This work aims at quantifying the amount of surface residual stress which reveals during cutting of the flat hot rolled strip. The head and tail part of the hot rolled strip ASTM A572 G50 Type-1 has been selected as the test specimen for the surface residual stress measurement. The specimen has been levelled and straightened through the levelling process. The quantification of residual stress has been completed using strain gauge method. This method provides an accurate means of measuring the residual stress within a component. In the measurement procedure, a strain gage rosette is attached to the area of interest and the shear cut of the strip is applied nearby the installed strain

rosettes in order to release the residual stress. The corresponding changes in the strain values detected by the strain gage measured with the help of strain indicator are substituted into the strain–stress equation in order to compute the residual stress within the component.

2. EXPERIMENTAL PROCEDURE

The head and tail end of the hot rolled strip has been selected for the residual stress measurement shown in figure 1 the head (a) and tail (b) end of the hot rolled strip. The hot rolled strip is levelled and straightened in the levelling section after the uncoiling process. Based on the concerned problem the head and the tail end of the hot rolled strip is considered as the critical region of the strip in which edge waviness, bending, twisting and central buckled defects take place during the cutting and uncoiling process. These defects cause due to non-uniform elastic-plastic deformation, phase transformation during the cooling process and stress relaxation at high temperature in hot rolled strip. The dimension of the specimen of 8mm thickness and 1500mm width from the head and tail end of the strip has been selected for the residual stress measurement. Strain rosettes were installed on the investigating locations to examine and see the variation of the residual stress at different locations i.e. the edge and center of the head and tail end of hot rolled strip.

Table 1 and Table 2 show the chemical composition and mechanical properties of ASTM A572 G50 TYPE-1 respectively.

Table 1 Chemical composition of the material.

C%	Mn%	Al%	P%	S%	Si%	N%	Nb%
0.18	1.3	0.05	0.025	0.05	0.08	100	0.012

Table 2 Mechanical properties of the material.

Elastic modulus (GPa)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	%Elongation
210	365	470	22

Figure 1 shows that the strain rosettes were installed on the three investigating locations i.e. right edge, center and left edge of the head end and two strain rosettes at center of the tail end of hot rolled strip. Afterwards, the strain was measured by P-3500 strain indicator before cutting process. The cutting process was used in order to relax the residual stress in flat hot rolled strip. For the measurement of residual stress, the steel strip was cut along the transverse and rolling direction for the head and tail end respectively. Based on the measured strain value residual stress was measured using strain rosette formulation which can be written as:

$$\sigma_{residual,\,x} = E \in_x + \vartheta\, \sigma_y$$
$$\sigma_{residual,\,y} = E \in_x + \vartheta\, \sigma_x$$

Where

$\in_x, \in_y$ = Normal strain in x and y direction

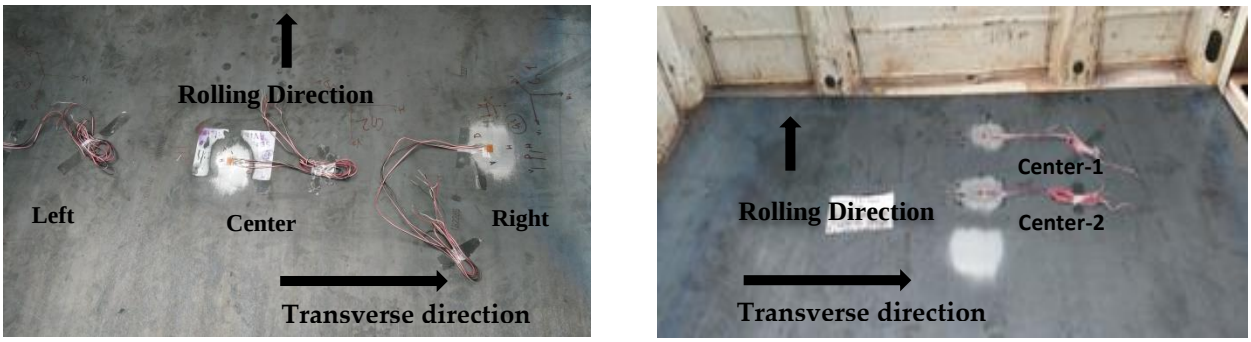
$\sigma_{residual,\,x}, \sigma_{residual,\,y}$ = Residual stress in x and y- direction

ϑ= Poisson's ratio

ϑ= 0.3

E = Young's Modulus

E = 210 GPa



(a) (b)

FIGURE 1. Installed strain gauge at- (a) The Head End, (b) The Tail end.

To see the variations of the residual stress after cutting process, Hot rolled strip was cut along and across the rolling direction. Fig 2 and fig 3 show the shear cut direction across the rolling in the head end and along the rolling in the tail end of the steel strip respectively. After the cutting process, strain was measured in the investigating locations by P-3500 strain indicator for both head and tail end of the steel strip.

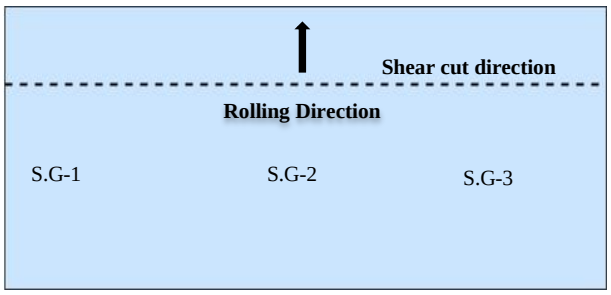


FIGURE 2. Shear cut across rolling direction in the head end.

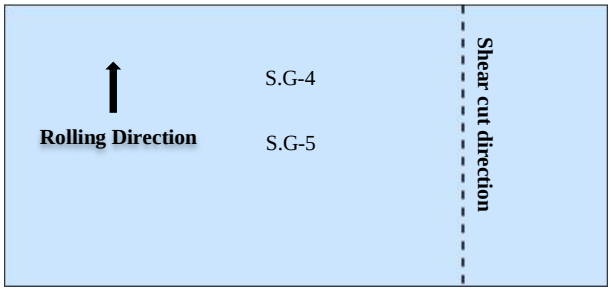


FIGURE 3. Shear cut along the rolling direction in the tail end.

FIGURE 4. Strain measurement **i**n steel strip after shear cut.

3. RESULTS & DISCUSSION

Mostly, the deformation problem because of the inducement of residual stress is generating after the shear cutting process in hot rolled strip. The residual stresses developed near the cutting section are determined at 3-locations in the head and 2-locations in the tail end of the hot rolled strip. The results were put together in Table 3. Results of measurements indicate that the stresses are distributed non-uniformly along the rolling and transverse direction in tail and head end of the strip respectively.

The relaxed residual stresses found were of tensile nature along the rolling direction and compressive nature along the transverse direction at the right and left edge of the head end after shear cut along the transverse direction. However, the amount of relaxed residual stresses was found higher as tensile along the rolling direction for the right

edge of the head end of the strip. The stresses were found of tensile nature along both the rolling and transverse direction at the center of the head end after shear cut off the hot rolled strip. The amount of residual stress increases in the rolling direction having tensile nature near to the cutting edges after cutting across the rolling direction.

However, in the tail end of the hot rolled strip, the relaxed residual stresses were found of tensile nature along the transverse direction in both the location of the center after shear cut along the rolling direction and compressive residual stress along the rolling direction. The amount of residual stress decreases in rolling direction at the central regions when the shear cut is applied along the rolling direction at the center.

Table 3 Measured values of residual stress after cutting process.

Cutting Direction	**Locations**	**Directions**	**Normal Strains** (μm/m)	**Residual Stress** (MPa)
Along Transverse direction	Right	Rolling	25	4.94
		Transverse	-12	-1.04
	Center	Rolling	75	17.17
		Transverse	-2	4.73
	Left	Rolling	12	2.42
		Transverse	-5	-0.32
Along Rolling direction	Center-1	Rolling	-20	-0.12
		Transverse	65	13.62
	Center-2	Rolling	-47	-6
		Transverse	70	2.9

4. CONCLUSION

Measurement of residual stress in hot rolled strip after shear cutting is considered. An experiment is carried out to examine the residual stress generated near the cut edges after the completion of the cutting process. The strain gauge method is used to determine the residual stresses near the region of cutting edges. It is found that cutting direction which is along the rolling and transverse direction and stress relaxation affects the generation of residual stress in the strip.

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