World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:8, No:12, 2014

The Effect on Rolling Mill of Waviness in Hot Rolled Steel

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Abstract**—**The edge waviness in hot rolled steel is a common defect. Variables that affect such defect include raw material and machine. These variables are necessary to consider to understand such defect. This research studied the defect of edge waviness for SS 400 of metal sheet manufacture. Defect of metal sheets were divided into two groups. The specimens were investigated on chemical composition and mechanical properties to find the difference. The results of investigation showed that the difference was not significant. Therefore the roll mill machine should be used to adjust to support another location on a roller to avoide edge waviness.

Keywords**—**Edge waviness, Hot rolling steel, Metal sheet defect, SS 400, Roll leveler.

I. Introduction

THE hot rolling steel sheet generally is a low carbon steel which are delivered, mainly, in normalized condition and cut to length sheet. Their sheet quality, including the flatness and sheet distortion, depend on the residual stress from the hot rolling process. The residual stress made the steel sheet wavy at its edge. The assumption of edge waviness was the changing of microstructure of steel in hot or warm rolling temperature. The cooling rate in the middle of the sheet was quicker than at the edge. The unstable cooling or unbalance cooling band in the width of steel had directly affected to steel microstructure. Therefore, this paper reviewed the microstructure of steel by using metallurgical method to verify the root cause of edge waviness.

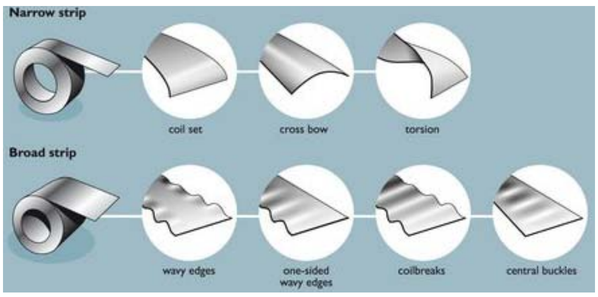

Fig. 1 Typical coil defects

This research studies the edge waviness during the process of manufacture. The steel coil was uncoilling from the roll to the first rolled mill as seen in Fig. 2. It continued on to the second rolled mill set. Then they were cut into sheets. It was found that the metal sheets were produced with edge waviness defect. Therefore the researcher focused on the finding ways to resolve the edge waviness defect through this study.

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Fig. 2 Process of uncoil and shear of coil steel

II. Literature Reviews

To control the properties of steel, both its composition and the applied heat treatment are of paramount importance. During the hot rolling process, the cooling process is of main importance to control the properties of steel. The effect of the cooling applies after hot rolling that is usually described with CCT diagrams as these describe the steel's transformation behavior under continuous cooling conditions. The transformational behavior is very sensitive to the chemical composition of steel [1]. Strain-induced dynamic transformation (SIDT) is of great advantage to obtain ultrafine-grained ferrite in low carbon steels partly by early impingement of ferrite nuclei which are very rapidly and concurrently formed due to the deformation and partly by the random crystallographic orientation distribution of ferrite grains. The SIDT fraction increases with the increase of strain. There is, however, a critical strain under which no SIDT occurs [2]. The mechanical characteristic of steel was changed during each sequence of sheet forming process [3]. The influence of %C in the range of 0.011-0.043 wt-% on the phase transformation characteristics, mechanical properties and microstructure of steel found that a reduction in the %C increased the phase transformation temperatures, decreased the hardness and promoted quasi-polygonal ferrite (QF) formation over granular bainitic ferrite (GBF) and bainitic ferrite (BF), but at the same time the sensitivity of the phase transformation temperatures and hardness to cooling rates was reduced. Microstructural analysis of the hot rolled plates showed that an increase in C content decreased the fraction of QF and consequently increased the fraction of GBF and BF, as well as the size and fraction of C-enriched secondary micro constituents. In addition, the size of the coarsest crystallographic packets seemed to be fine in the low C steel with QF dominated microstructure than in its higher C counterparts with higher fractions of GBF-BF, even thought the average crystallographic packet size was slightly better in these higher C steels. Mechanical testing showed that toughness properties were not strongly dependent on %C, although toughness was slightly weaken with increasing %C [4]. It has been observed that flatness deterioration can be caused by non-uniform water cooling across the strip width during strip transport through laminar cooling on the run-out table, which is a result of excessive thermal contraction in the over-cooled strip edges. Hot bands that were rolled perfectly flat, or even with a slight center buckle in the finishing stands, developed considerable two-sided waviness that was observed during hot strip uncoiling after coil cooling to ambient temperature. The excessive waviness resulted in extra yield loss and additional processing cost incurred because temper rolling was required to remedy the poor flatness [5].

The microstructures of 0.37C-0.87Mn steel containing ferrite and martensite, they were produced by the intermediate quenching method with annealing at different temperatures followed by water quenching. During the annealing, the austenite nucleates and grows at former boundaries of the martensite plates, resulting fibrous microstructure of martensite and ferrite. It was observed that increasing annealing temperature increases the amount of martensite and hardness [6]. The principles of non-destructive electromagnetic technique to detect and monitor the austenite-to-ferrite phase transformation is allowing for process modifications to better and dynamic control of the microstructure in hot rolled bands [7].

III. Experiment

The steel sheet (SS400), by different suppliers was to uncoil for mill before being cut into sheets. The steel sheet product appear the edge waviness at the edge of a steel sheet as shown in Fig. 3. Therefore, the steel sheet are examined into the mechanical properties, microstructure and chemical composition to find the causes that affect the edge waviness of the steel sheet.

The steel sheet SS400 was analyzed with a chemical composition is shown in Table I. The steel sheets were involved into two groups: flat and waviness edge defect. The steel sheets were cut along the longitudinal and cross on section at the edges and the center of the steel sheet for tensile testing . While at the same position on the steel sheet will be taken to determine the microstructure and chemical composition. The results will be compared and analyzed.

TABLE I
The Chemical Composition and Mechanical Properties of the Steel Sheet Ss400

C	Mn	Si	S	P	Fe
0.148	0.458	0.213	0.018	0.012	Bal.
Elastic Modulus (Gpa)		Tensile Strength (Mpa)		Yield Strength (Mpa)	
209		400		245	

Fig. 3 Sample of edge waviness defect

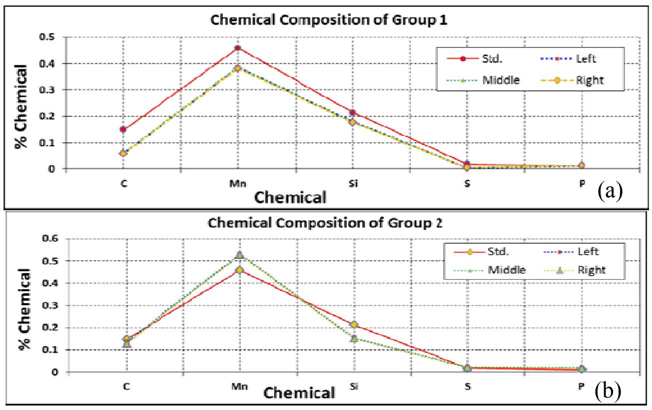


Fig. 4 The results of chemical composition at left middle and right on specimens (a) Group 1 and (b) Group 2

IV. Result

The flat steel sheet and edge waviness was examined the difference with the tensile test, chemical composition and microstructure. All results were compared. The chemical compositions of the edge waviness defect of the two groups were shown in Table II. The specimen was examined the chemical composition that found: group 1 was approximately

0.059%c at the edges on both sides and the center in Fig. 4 (a). The group 2 showed that were significantly higher than group 1 (Fig. 4 (b)).

TABLE II
THE CHEMICAL COMPOSITION OF TWO GROUPS WITH EDGE WAVINESS DEFECT ON METAL SHEET SS 400

Group	Chemical	Position		
		Left	Middle	Right
1	C	0.059	0.059	0.058
	Mn	0.384	0.385	0.381
	Si	0.177	0.178	0.174
	S	0.003	0.003	0.004
	P	0.011	0.011	0.011
	Fe	99.120	99.118	99.129
2	C	0138	0.134	0.129
	Mn	0.532	0.529	0.528
	Si	0.153	0.152	0.151
	S	0.021	0.021	0.020
	P	0.018	0.018	0.017
	Fe	98.970	98.981	98.987

When comparing the standard steel sheet SS400 with 0.148%c and edge waviness into 2 groups found that the group 1 was less proportionate than the standard. While group 2 was close to standard. The manganese is 0.458%Mn for standard. The group 1 was similar to the standard with 0.38%Mn. And group 2 shows that the specimen is slightly greater than the standard with a 0.52%Mn. The silicon standard was 0.213%Si. While the edge and the center were similar silicon less than the standard.

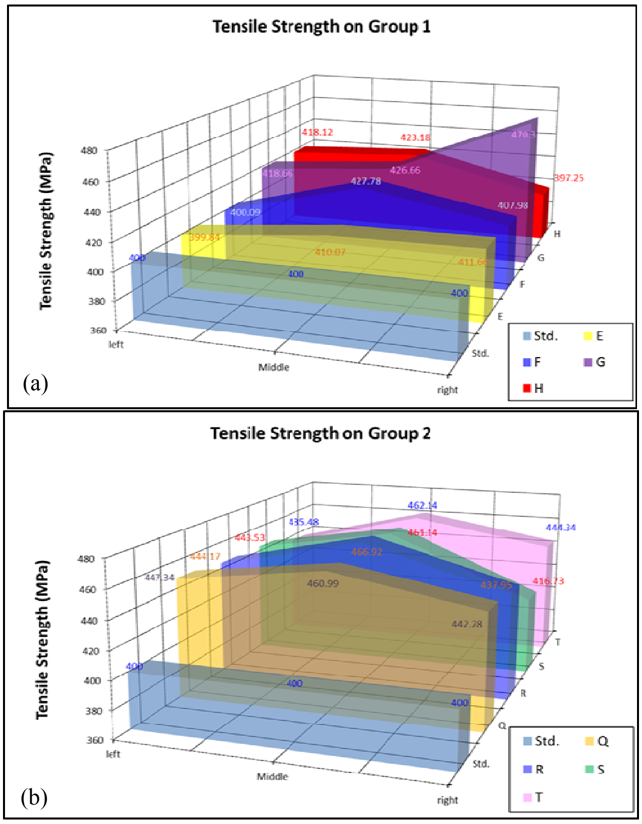


Fig. 5 The tensile strength of steel sheet with edge waviness
(a) Group 1 and (b) Group 2

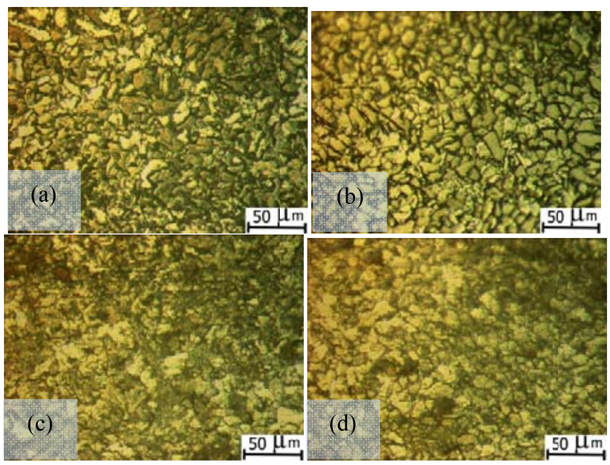
While the tensile strength of steel sheet SS400 is shown as Fig. 5 which showed that the standard is 400 MPa. The specimen with the two groups was found that the tensile strength of group 1 with the different results by the center was higher than the standard of 421 MPa, while the left of edges was higher than at 442 Mpa and the right edge at 421 Mpa. The group 2 were different of tensile strength with the standard as well. The center has an average elevation of 462 MPa of tensile strength which is more than the egdes at an average of 422 MPa and 435 Mpa on the left and right edges, respectively.

While examining the microstructure of steel sheet SS400 with the two groups of edge waviness showed that the two groups have a grain size difference. The group 1 demonstrated the growth higher than group 2 in grain size. The group 1 found that the center and the lateral edge was similar in grain size (Figs. 6 (a)-(f)), while the second group showed a smaller grain size. The grain at surface and cross section in different areas with similar characteristics as Figs. 7 (a)-(f).

V. DISCUSSION

Considering chemical composition, tensile strength and microstructure found that the two groups are. Variables affected the edge waviness defects on the steel sheet SS400 includes the input in the process such as: sizes of the slab before rolling, rolling, heating and cooling. These input affected the mechanical properties. Therefore, considering the edge waviness defect was very complicated that the data was limited, thus the analysis can not be done perfectly.

While the manufacturing process was included with uncoilling, rolling and cutting that affected to the product. The machine was composed with a lot of rollers. It can be classified into three strages. Stage No.1 is leveling which is achieved by precisely bending metal strip back and forth as it's passed through a series of small-diameter offset rolls. The gap between the rolls is set independently on a leveler's entry and exit. To level, entry rolls were deeply nested. That forced the material to pass through extreme angles to erase memory caused by trapping internal stresses. It's also called the plunge, a technique for removing strip memory.



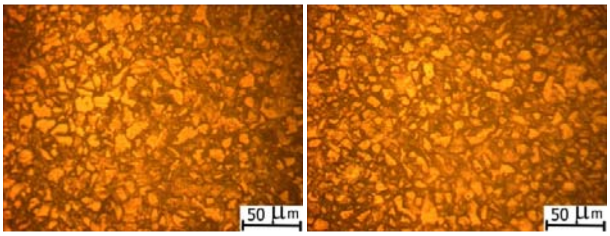
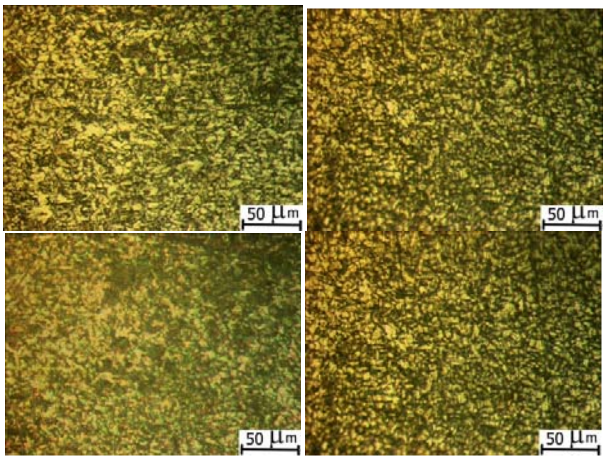


Fig. 6 The microstructure of the edge waviness defect of the specimen in Group 1 is different at (a) the cross section of the center (b) the cross section of the edge (c) the cross section in the direction of rolling on the center (d) the cross section in the direction of the rolling on the edge of the specimen (e) the center of the specimen surface and (f) the surface of the edge of the specimen

In stage No.2, a leveler uses adjustable pressure points called flights under the roll to raise and lower them to a precise position. By adjusting a work roll's shape, you can alter the material path length through the leveler. A longer path length allows material to be stretched more because more work is being performed on it as it passes through the rolls. Lastly, in the stage No.3, it's time to reset the strip's memory to flat as it leaves the leveler. The appearance of the material shipped to the end user is achieved in the final three roll clusters. If the roll gap is set too deep, the material will be forced upward by the last roll, creating up-bow. It's normal to set the leveler's exit gap near the material's gauge, a simple but important rule of thumb. Therefore, if the machine can control the flow of steel sheet through the roller set. The edge waviness defect can be eradicated.

While the processing of metal sheet, which is the process for a rolled mill and cut on the metal sheet that affects the product. The rolled mill machine includes roller which can be classified into three groups: Remove Memory, stretch and reset memory as presented in Fig. 8. Therefore the rolled mill machine is a variable that affects the product significantly, especially the roller set. The rollers move through the roller set and bend (Fig. 9) which effect for tensile stress and compressive stress above the yield point on both surfaces, which causes for changes in size and shape.



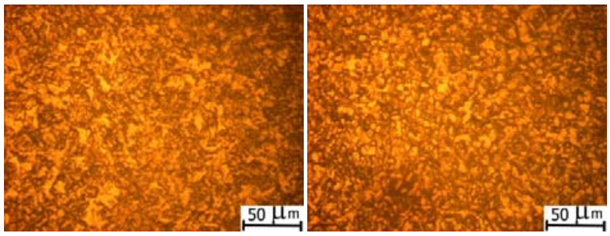


Fig. 7 The microstructure of the edge waviness defect of the specimen in Group 2 is different at (a) the cross section of the center (b) the cross section of the edge (c) the cross section in the direction of rolling on the center (d) the cross section in the direction of the rolling on the edge of the specimen (e) the center of the specimen surface and (f) the surface of the edge of the specimen

Fig. 8 The process of rolled mill for metal sheet consists of remove memory, stretch and reset the memory

As the neutral axis of the sheet metal is not affected by the bending stress, it exceeds to the yield point of the material, therefore the neutral axis has flexible and spring back that affect to flat for the product. Therefore, it is necessary to have a tensile stress occurred during rolling process. There is a neutral axis of sheet that has a tensile load exceed yield point. It causes deformation at the neutral axis. The roller effected to exceed the tensile stress at the neutral axis in metal sheet during the operation. So tensile stress is also depends on other factors as well, especially the height of the upper and lower roller set.

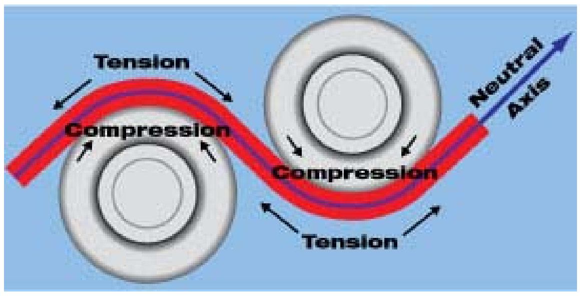


Fig. 9 The roll move through the roller set and bend which effect for tensile stress and compressive stress above yield point on both surfaces

The quality of the roller set also affects the quality of the product. The roller set such as Flattener, Straightener and Shape correction leveler, the three characteristics that must be used accordingly.

The Flattener (Fig. 10) is designed to be supported with bearings at both ends. Usually there are 4-7 rollers, so it is less effective to roll the mill only 10-20% of the yield point. Only the capable of remove coil set may reduce some crossbow. Working with the flattended hard material can actually induce edge wave.

The straightener as seen in Fig. 11 is designed to have all the backup bearing surface of 10-20 rollers. Formability approximately 50% to 70% of material in yield. Normally designed for narrow strip but can be designed for wider strip. In general, a much more precision machine performs better than a flattened. Operation characteristics includes the removal of: coil set and cross bow and maybe some edge wave and center buckle. Typically lighter gage materials are used, there can be heavy gage also as needed.

Shape correction leveler as seen in Fig. 12 is designed to have the back support bearing round surface of the roller. Backup bearing rails either on the top or bottom can be adjusted up and down individually to bow or bend the work rolls. Normally have larger number of 10 to 20 rollers. Close roll spacing with smaller diameter rolls. Formability approximately 50% to 80% of material in yield. Normally shape correction leveler was designed for wider strip. In general it was more precision machine. The operation characteristics consist of: the removal of a coil set, cross bow, edge wave, center buckle and combinations. The machines are built from all gage materials, but the common are of 0.015 "to 0.250".

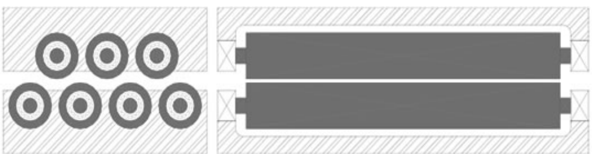


Fig. 10 The Flattener is designed to be supported with bearings at both ends

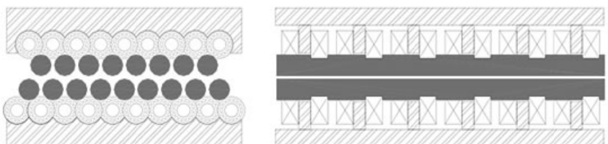


Fig. 11 The straightener is designed to have all the backup bearing surface of 10-20 rollers

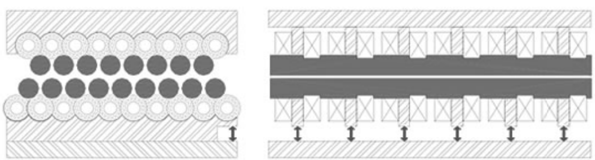
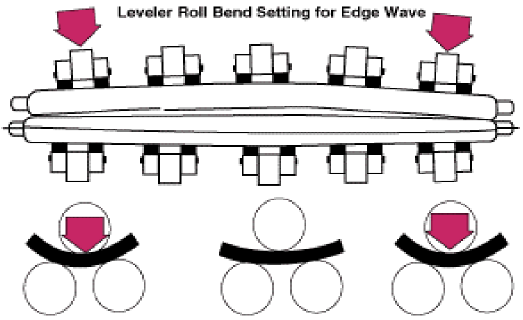
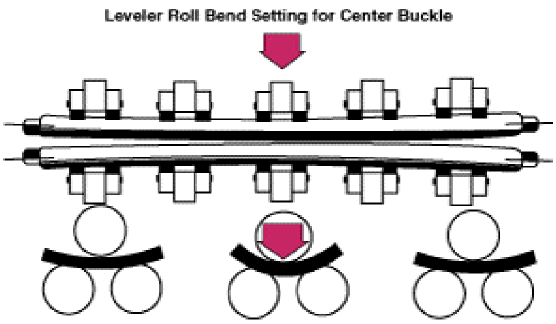


Fig. 12 The shape correction leveler is designed to have the support back bearing round surface of the roller

The principle of roll leveler that is widely used to identify a leveler roll bending for edge wave and leveler roll bend setting for center buckle as seen in Fig. 13. The main difference between them were a position of the support on a roller mill. Therefore, the control support must be proper to make a complete product.



(a)



(b)

Fig. 13 The principle of roll leveler that is widely used to identify a 2 such as (a) Leveler roll bend setting for edge wave and (b) Leveler roll bending setting for center buckle

While rolling process is shown in Fig. 14, which consists of two roller set as leveler A and leveler B set. Both the roller sets consist of 5 rollers and the support to both ends. When analyzing the number of rollers on the three characteristics of the machine as shown in Figs. 10-12 found that the machines in the manufacturing process are flattener type by only 4-7 rollers and without backup bearing support them. Therefore the flattener type is not suitable for the curvature steel sheet. Since the number of the roller for leveler A is less that not enough of tension stress on yield point. Although the leveler B repeats rolling, the bending stresses that occur on the surface while performing was insufficient for the metal on the neutral axis.

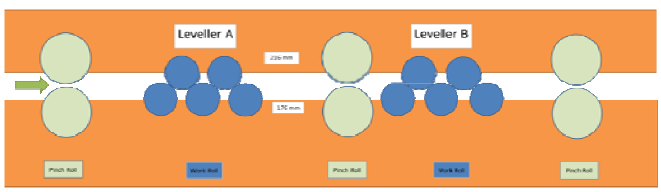


Fig. 14 While rolled mill machine in the manufacturing process consists of two roller set is set Leveler A and Leveler B

While the roller is controlled at both ends without being able to adjust in another location, it remains edge waviness in steel sheet.

VI. CONCUSSION

The results of chemical composition and mechanical properties of the two groups showed no significant difference with the standard. While the rolled mill manufacturing process on the machine that has the limited capability could not achieved to goals. So the machine should be used to adjust to support another location on a roller to avoide edge waviness.

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