Analysis and Improvement of Warpage Cause of High Strength Steel in Commercial Vehicle

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Abstract—Aiming at the warping problem in high strength steel of commercial vehicle, it is concluded that the flatting machine is the main factor leading to the warpage of the strip through the plate shape tracking experiment, the reason for the deterioration of the warpage with the increase of yield strength is expounded. Analysis points out that the difference of the friction coefficient between the upper and lower rollers and the difference of the roller diameter will result in the deterioration of the plasticity after leveling. According to the high strength characteristic of the automobile steel, the measures for improving the original plate shape, reducing flat rolling pressure and the diameter difference of the work roller are developed, good application results have been obtained.

1. Introduction
Plate shape is one of the main quality control objectives of hot-rolled strip, the difficulty of shape control is increasing as the product develops towards the limit of higher strength, wider width and thinner thickness. Because of the special needs of processing and use, the flatness warpage requirement is within 5 mm, which is far lower than the national standard requirement, this puts forward the extremely high requirement to the flatness control level. Commercial vehicle high strength steel is the key variety of 1780 mm hot continuous rolling unit of Angang, with annual output of more than 1.2 million tons, which has a very high share in the market, but the warping problem of flatness has not been effectively controlled. In order to ensure the precision of delivery flatness and expand the range of flatness specifications, it is expected to reduce the flatness defect by leveling means, but the number of flatness dissent does not drop but rise, which becomes a bottleneck problem that seriously restricts production.

2. Present Situation
According to the statistical analysis of the quality objection of 1780 mm hot rolling production line of Anyang Iron and Steel Stock Co., Ltd., it is found that more than 70% of the plate quality objection is steel for automobile construction machinery. From the distribution of specifications and varieties, the main features are thin specifications, wide section, high strength, and the investigation shows that more than half of the plate defect rolls are flat steel coils. The shape of these defect coils shows well during leveling, and after longitudinal or cross-cutting by the user, various warping phenomenon appears along the plate surface longitudinal or horizontal, such as Lwarp, Cwarp, Four corners, etc., as shown in Figure 1, figure 2, figure 3. Because the defect is not visible at the time of leveling, there is a lack of effective means in control. And the production line is not equipped with decoiler machine, so the defects are often exposed when it delivers to the users.
3. **Analysis of Causes**

The main purpose of the hot rolling levelling process is to make the strip produce proper deformation by applying a certain elongation to the incoming material, so as to obtain a good shape, and at the same
time, it has the function of improving the performance and the surface quality. But the original shape state will be destroyed, which will easily lead to the deterioration of plasticity, and a new shape problem is added to the existing shape defects.

The flatness defect is essentially the result of the inconsistent longitudinal extension strain of the strip steel. Zhang Qingdong et al. [1] pointed out that the extension unevenness in the direction of strip thickness induces the transverse uneven distribution of strip steel, so residual stress is generated inside the strip. When the strip is not cut, it can not be displayed when the strip is flat because of the mutual coordination of each part of the strip. When the strip is cut in decoiler machine, the coordination between the original parts is broken and the stress distribution is reshaped. The edges and corners formed after cutting are warped due to loss of restriction. The transverse elongation will produce C warp when the thickness direction is uneven, the longitudinal elongation will produce L warp when the thickness direction is uneven, and the two forms four corners warp at the same time. Reference [1] at the same time, it is pointed out that the warpage of the strip decreases with the increase of the strip thickness, and the warpage increases in quadratic relation with the increase of strip width, which is consistent with the characteristics that the shape problem is mostly thin specification and wide section.

3.1. Effect of strip shape on warp
In the cooling process of the strip steel, too large cooling speed difference between the transverse side and the middle part of the coil is easy to form a small period of side waves, which is more serious with the thickness thinning and the widening of the section. V. B. Ginzburg points out [2] that the flatness defects in the width direction due to the temperature gradient show a significant side wave or small side wave form. Cai Zheng's research also shows that the tensile stress in the middle of the strip and the compressive stress in the side are caused by the transverse temperature distribution of the side temperature drop of the strip steel, that is, the stress caused by the temperature drop in the cooling process makes the strip shape develop towards the edge wave direction [3]. Too small rolling pressure is invalid for shape correction when levelling. For this reason, larger elongation than that of the common carbon steel is often used to eliminate the flatness defects. And too much levelling pressure will bring more residual stress, which will cause warping, and this defect is usually unpredictable before cutting, so it is difficult to pre-control.

3.2. Effect of yield strength of strip steel on warpage
The yield strength of commercial high strength steel is generally high, and the shape control is difficult when rolling. The study [4] pointed out that the residual stress value of the strip is increasing with the yield point of the strip, the higher the yield strength of the strip, the greater the plastic strain difference, the greater the warpage of the strip, as shown in figure 5. Through the levelling experiment of different strength strip, see Table 1, the warpage of high strength strip at the same elongation is significantly larger than that of plain carbon steel and low carbon soft steel. So the plate shape of the high strength strip has the following characteristics: the residual stress of strip will be larger during the cooling process after rolling, the plastic strain difference will be greater when levelling, and the warpage is more likely to occur. The above view can explain reasonably that why the high strength steel is more likely to appear quality defect of plate shape.
3.3. Effect of drive mode on warp

Angang 1780 mm hot continuous rolling leveling unit is a four-roll single frame leveling machine without channeling roll, the driving mode is the lower support roller drive, the driving torque is transferred from the lower work roll to the rolled pieces, then to the upper work roll, finally to the upper support roller through the friction between rollers in turn. The characteristics of the lower support roller drive determine that the speed difference of the upper and lower rollers will be produced when the roll rotates, which makes the leveling machine have the characteristics of asynchronous rolling, this leads to the inconsistency of the speed of the upper and lower surfaces of the rolled pieces, and the speed difference between the upper and lower surfaces causes the extension difference between the upper and lower surfaces during flat rolling, thus resulting in warpage. This is also consistent with the research results in reference[4], that is, the amount of the strip warpage increases linearly with the increase of longitudinal extension difference of the upper and lower surfaces of the strip.

3.4. Effect of work roll diameter difference on warpage

According to the investigation of the work roll distribution condition of leveling machine, the result is as shown in Table 2, it is found that the configuration of the roll diameter difference is random. Reference [5] analyzed the effect of the roll diameter difference on the L warp of the strip by rolling experiment. On the one hand, because the characteristics of the drive of the lower support roller of the leveling machine will lead to the speed difference between the upper and lower surface of the strip, which will cause the extension difference and produce warpage; on the other hand, assuming that the linear speed of the tail roll is consistent with that of the drive roll, the excessive roll diameter difference will also lead to the longitudinal extension of the upper and lower surface of the strip, when both act together, they exacerbate warping. When the work roll of leveling machine is matched, the roll diameter difference configuration is random, and sometimes the diameter difference between the upper roll and the lower roll can reach more than 3 mm, which will aggravate the extension difference of the upper and lower surface of the strip.

### Table I. Comparison of-warpages between different strength steel measured in decoiler machine

| Steel | Thickness | Width  | Extension | Warping |
|-------|-----------|--------|-----------|---------|
| SPHC  | 2.9mm     | 1270mm | 2%        | 13mm    |
| Q235  | 2.5mm     | 1500mm | 2%        | 17mm    |
| 510L  | 2.9mm     | 1500mm | 2%        | 28mm    |
| 700L  | 3.0mm     | 1500mm | 2%        | 33mm    |
TABLE II. SURVEY ON THE DIAMETER DIFFERENCE OF UPPER AND LOWER ROLLER FOR FLATTENING MACHINE

| Serial number | Upper roll diameter | Lower roll diameter | Roll diameter difference |
|---------------|---------------------|---------------------|--------------------------|
| 1             | 486.92mm            | 485.24mm            | 1.68mm                   |
| 2             | 494.39mm            | 495.28mm            | -0.89mm                  |
| 3             | 474.26mm            | 477.76mm            | -3.50mm                  |
| 4             | 490.02mm            | 490.44mm            | -0.42mm                  |

4. Improvement Measures

4.1. Improvement of Strip Shape after Rolling to Ensure Initial Strip Shape before Levelling

The flatness problem is brought about by the poor shape after rolling in a certain extent, so in the control strategy, the levelling machine should be avoided as the terminal to solve the flatness problem, the initial shape before levelling should be guaranteed by improving the original shape of the strip, thus reducing the over-levelling of the strip and reducing the accumulation of residual stress of the strip. According to the characteristics of edge wave after strip rolling, especially for high strength, thin specification and wide section strip, the field practice shows that, when the performance meets the requirements, it can greatly alleviate the side wave defects after rolling by raising the coiling temperature and reducing the laminar cooling rate properly. For example, the coiling temperature of the steel AG600XT is raised from 620℃ to 640℃, and the cooling mode is changed from continuous cooling to sparse cooling. From the flatness condition of plate after decoiling, the trend of bilateral wave is obviously weakened. At the same time through the measures including the hot coil downline centralized stacking cooling and slow cooling into the cooling pit, the shape problem of the plate caused by excessive cooling speed difference during rolling can be effectively improved.

4.2. Specification of flat rolling pressures for different strength steels

When levelling, if the shape is poor, operators usually use the method of increasing rolling pressure to eliminate the wave shape, sometimes flat rolling pressure will be increased to more than 4000 kN, however, too large flat rolling pressure will lead to greater residual stress accumulation inside the strip, this steel coil is flat after the surface straight, but severe warping will occurs when horizontal or longitudinal cuts are carried out by the user after decoiling. Therefore, the flat rolling pressure is regulated for different strength steels. The set range of the rolling pressure is 2000—2500 kN for low grade steel and 2500—3000 kN for high grade steel, maximum not exceeding 3000 kN. For the variety specification with higher requirement of shape warpage, when the original plate shape is relatively good, a smaller rolling pressure should be adopted to smooth the plate shape within the specified range, when the plate shape is relatively poor, the wave shape can’t be eliminated simply by increasing the rolling pressure, the rolling pressure can be increased appropriately, the rolling speed can be reduced, and the bending roller force can be adjusted reasonably according to the shape condition to improve the shape of the plate, so as to avoid the large residual stress difference due to excessive flat extension.

4.3. Standardizing the roll diameter difference between the upper and lower rollers of the work roll of the levelling machine

The upper and lower roll diameter difference configuration of the work roll of the levelling machine is regulated, the diameter difference between the upper and lower roll is required not more than 0.5 mm, and it shall be strictly carried out. It is strictly forbidden to configure the roll diameter at will, so as to reduce the extension difference of the upper and lower surfaces caused by the excessive roll diameter difference, and reduce the warping of the plate belt caused by it.

5. Conclusions

1) The defect of sheet warpage is the result of the residual stress caused by the deterioration of plastic strain, which increases with the increase of yield strength of strip.
2) Levelling is the main process to produce warpage defects. Because it has the characteristics of shape correction and increasing residual stress accumulation at the same time, it is necessary to improve the original shape to ensure the shape before levelling, and not eliminate the wave shape simply by increasing the flat rolling pressure.

3) The warping of the strip can be improved by means of the hot coil downline centralized stacking cooling and slow cooling into the cooling pit, standardizing the rolling pressure and optimizing the roll diameter difference.

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