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Low Temperature Rolling Technology for Coil Shape Optimization of Hot-Rolled Medium Carbon Steel

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Hot-rolled medium carbon steel SAE 1050 is mostly used in hand tools, washers, and seat belt parts. To meet the customer's processing and forming demands, a high coiler temperature design (CT: 680°C) was adopted to obtain lower hardness. However, the rejection rate of the leaf mark defects of high CT medium steel was increased significantly to more than 10% during 2021. It is known that a coil is prone to reheat and collapse because of the release of latent heat after coiling, resulting in the leaf marks with gouges. To improve these defects, the laminar cooling middle temperature (MT) is reduced from 700 to 650°C to release the latent heat in advance, and the finish temperature (FT) is reduced to 850°C to optimize hardness performance. Additionally, to avoid coil collapse, we increased the tension and time that the coil hung on the mandrel of the coiler to enhance the support of the inner ring. The line speed of the temper & recoil line (TNRL) was also restricted to prevent gouging caused by the oval coil shape when uncoiling. Finally, the rejection rate of the leaf marks of SAE 1050 decreased from 4.83% to 0.25%, with an improvement of more than 90%.

Keywords: SAE 1050, Medium carbon steel, Latent heat, Coil shape, Leaf mark, Gouge

1. INTRODUCTION

The high coiler temperature design (CT: 680 °C) in the hot strip mill (HSM) was adopted to obtain lower hardness for hot-rolled medium carbon steel SAE 1050, which can meet the processing and forming requirements of customers, mostly used for hand tools, washers, and seat belt parts. However, the high CT could result in the phase transformation to be delayed, causing the coil to release latent heat after coiling, finally resulting in reheating and causing oval deformation in the coil. Leaf mark defects can occur during the uncoiling because of inter-laminar compressive stress of the coil after the temper & recoil line (TNRL). More seriously, the defects will be accompanied by gouge marks that cause the coil to be rejected. (Fig.1 and 2)

During the delayed phase transformation of the pearlite of medium carbon steel, the latent heat of transformation will be released. Figure 3 shows the latent heat releasing characteristics of medium carbon steel (0.54% C), compared with low carbon steel (0.10% C) (Fig.4), the latent heat difference is obvious. Therefore, for coils with higher CT, the phase transformation occurs during and after coiling, and the temperature of the coil keeps rising after the latent heat is released.

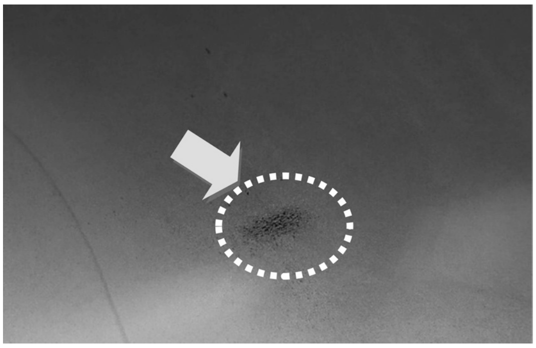

Fig.1. Leaf mark defect

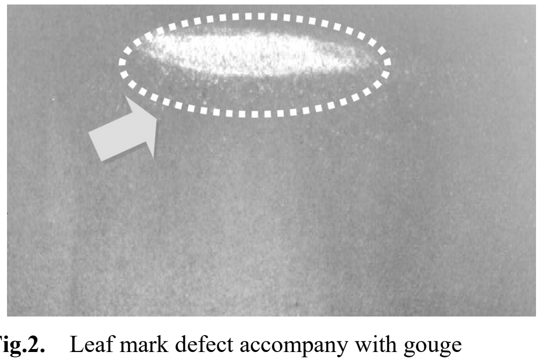

Fig.2. Leaf mark defect accompany with gouge

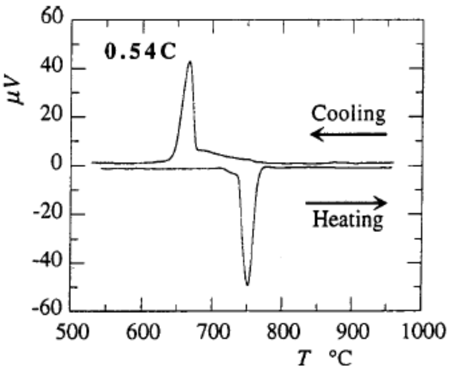

Fig.3. The latent heat release of medium carbon steel (0.54% C)

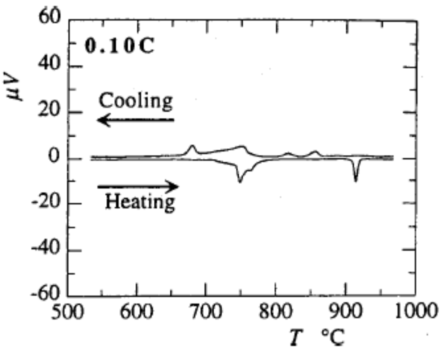

Fig.4. The latent heat release of low carbon steel (0.10% C)

During the coil cooling process, the inner ring of the coil is rapidly cooled because of being in contact with the mandrel of the down coiler, and which volume will expand firstly when the phase transformation begins. When the coiling process finishes, the volume of the inner ring starts to shrink as the temperature decreases. Conversely, the volume of the outer ring starts to expand. The volume difference of the inner and outer rings increases the distance between the layers of the coil and decreases the density of the coil. Finally, the coil starts to collapse and deform into an oval shape (Fig.5), resulting in leaf marks and gouge defects when uncoiling at subsequent TNRL.

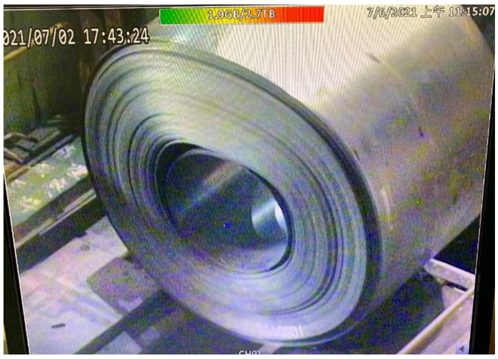

Fig.5. The collapsed oval shaped coil

After the hot-rolled band produced in the HSM, the theoretical value of the inner diameter should be 762mm, the coil has a circular shape and there is no obvious gap between the strips. Observing the coils with leaf mark defects, the inner diameter measured by the coils shape meter is between 698 and 737 mm, which is obviously smaller than 762 mm. It is concluded that the latent heat is not fully released in the laminar cooling zone of the HSM, resulting in reheating and collapse after coiling. When the TNRL produces elliptical coils, generally it depends on the severity of the collapse of the coils, the line speed is lowered to reduce the leaf mark and gouge defects caused by uncoiling vibration and friction. Therefore, the rolling speed is included as an impact factor.

From 2020/6 to 2021/6, the relationship between CT and the rejection rate of leaf mark defects of all SAE 1050 produced in #1HSM are shown in Figure 6. It can be found that the output and the rejection number of the

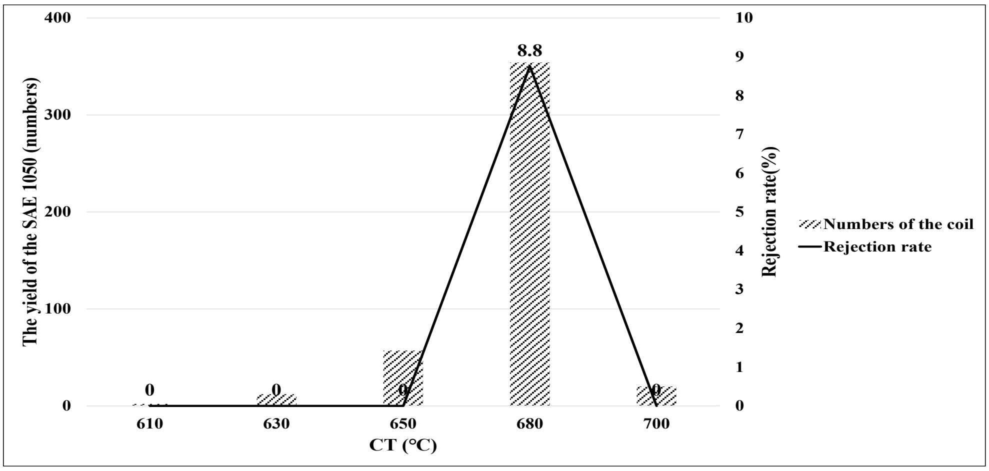

Fig.6. Rejection rate of the leaf mark defect under different CT conditions

leaf mark defects were mostly of high CT (680 °C) coils. The leaf mark and gouge defect rejection rate of SAE 1050 with high CT design are as shown in Figure 7. The highest and lowest rejection rates are 13.02% and 0% respectivily, and the average being 4.83%.

2. EXPERIMENTAL METHOD

2.1 High Coiler Temperature (CT)

To meet the customer's processing formability requirements, the target CT is not changed, and we improve the medium carbon steel by adjusting the laminar cooling mode of the HSM. Using the finish temperature (FT) and the laminar cooling middle temperature (MT) as procedure parameters, to complete the phase transformation advanced in the laminar cooling zone.

2.2 Coil Shape

To enhance the support of the inner ring and reduce the possible collapse of the coil, the coil shape produced by hot rolling can be improved by the following:

(1) Increasing the coiling tension.
(2) Reducing the length of the top and tail of the coil during hot-rolling.
(3) Increasing the time that the coil is hung on the mandrel of the down coiler.

2.3 Uncoiling of TNRL

Controlling the line speed of TNRL during uncoiling to improve the interlayer slip phenomenon. In particular, the closer to the end of inner ring, the more obvious is the degree of leaf mark defects because the inner ring is more stressed than the outer ring.

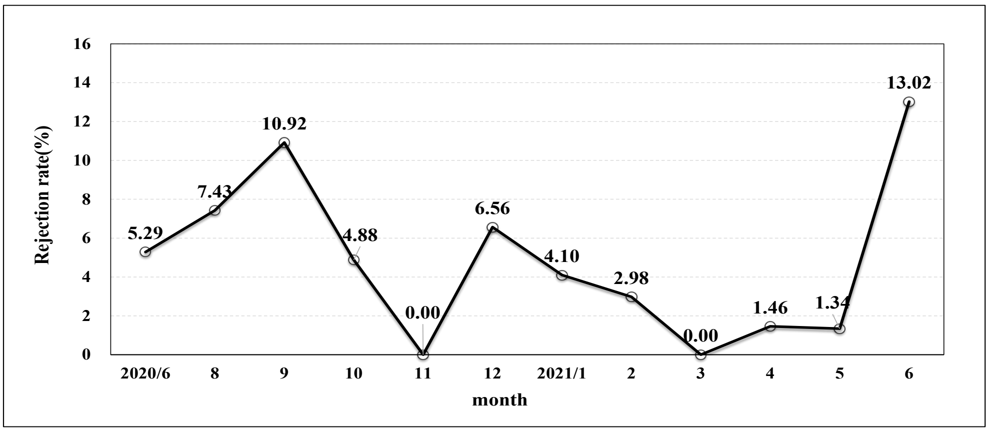

Fig.7. Rejection rate of leaf marks.

Binary Logistic Regression: Detection rate versus FT, MT, CT, Line speed

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Link Function: Logit

Response Information

Variable        Value  Count
Detection rate    Y       83  (Event)
                  N      372
                Total    455

Logistic Regression Table

                                                        Odds      95% CI
Predictor       Coef      SE Coef       Z       P      Ratio   Lower  Upper
Constant    -13.6803     13.7951     -0.99  0.321
   FT       -0.0021280  0.0072565   -0.29  0.769    1.00    0.98   1.01
   MT        0.0241052  0.0070293    3.43  0.001    1.02    1.01   1.04
   CT       -0.0021690  0.0154587   -0.14  0.888    1.00    0.97   1.03
Line speed  -0.0052063  0.0013448   -3.87  0.000    0.99    0.99   1.00

Log-Likelihood = -185.728
Test that all slopes are zero: G = 60.830, DF = 4, P-Value = 0.000
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Fig.8. Logistic regression of the detection rate with factors.

We have used logistic regression to analyze factors, including finish temperature (FT), layer cooling middle temperature (MT), coiler temperature (CT) and TNRL line speed, and it indicated MT and TNRL line speed are the most significant variables, which P values are both less than 0.05. (Fig.8)

3. RESULTS AND DISCUSSION

3.1 Lower MT Test

From 2020/6 to 2021/6, the average MT is 690-710°C. In July, the setting of the laminar cooling zone was adjusted by increasing the cooling water volume, the MT was lowered to 645-660 °C, to facilitate the advance release of latent heat in the laminar cooling zone.

3.2 Lower FT Test: Hardness Improvement

Since the MT has been lowered to release the latent heat in advance, there has been an improvement in the leaf mark defect trend. However, the hardness of some coils is likely to exceed the upper limit of the customer's specification (≦94HRB).

Therefore, we adjusted the FT from 890/875 to 850°C by low-temperature rolling to approach the Ar3 temperature. The grain size of austenite is refined after rolling, and many dislocations are introduced in the process. The dislocations are also the nucleation point of cementite during the phase transformation. Therefore, after the phase transformation, the grains of cementite are refined, and then the intermittent cementite can be achieved by high coiling temperature, which further increase the nucleation density of the ferrite. When the ratio of ferrite increases, the hardness reduces. Additionally, lowering the FT can also reduce the temperature difference between the target of FT and MT, which is beneficial for the MT to meet the target. After improvement, the average hardness of the coil is 89-91 HRB. (Fig.9 and 10)

3.3 Coil Shape Improvement

Reducing the length of the top and tail of the coil during hot-rolling could intensify the strength of the coil. Increasing the tension of the coiler could increase the density of the coil when coiling and avoid sliding when uncoiling by TNRL. Additionally, increasing the time that the coil is hung on the mandrel to 60 seconds, to enhance the support of the inner ring and prevent the collapse of the coil. The improvement effects are as follows:

(1) The inner diameter is 698-737 mm before the improvement, and about 720-760 mm after the improvement,

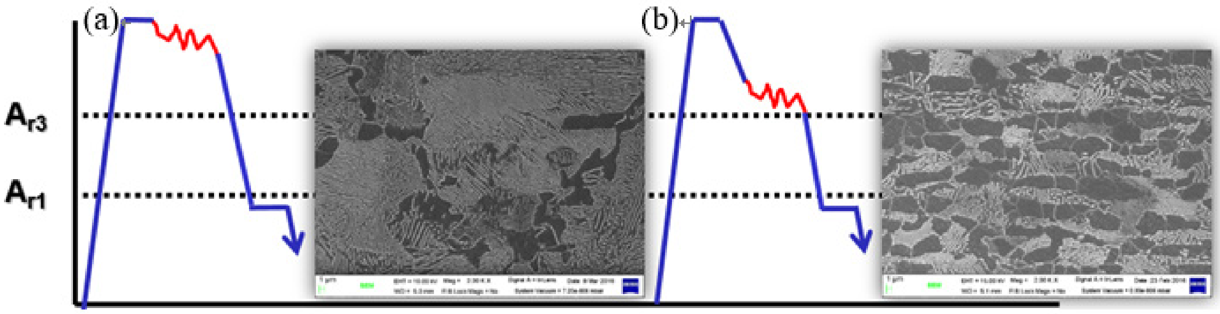
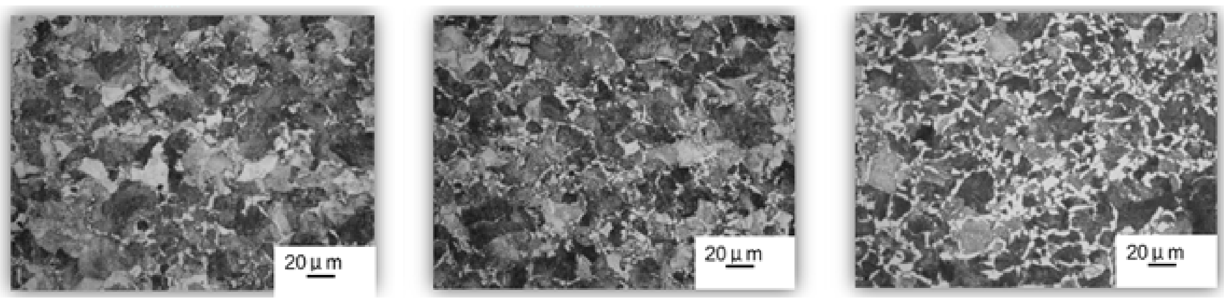


Fig.9. Medium carbon steel (S50C) schematic diagram and SEM (a) Traditional high temperature rolling; (b) Low temperature rolling process.



(a) (b) (c)

Fig.10. (a) FT=870°C，97HRB；(b) FT=830°C，94HRB；(b) FT=810°C，92HRB.

which obviously improves the collapse phenomenon.

(2) After the improvement, the rejection rate of the leaf mark was reduced from 0.07% to 0.008%.

3.4 Optimization of the Line Speed of TNRL

To reduce the occurrence of the leaf marks and gouge defects during the production of the TNRL, slow line speed is adopted for elliptical coils. In the analysis of the coils rejected by the leaf mark, the line speed of #2TNRL is from 120 to 240 mpm.

The maximum line speed of program control is changed to 100mpm for SAE 1050, which reduces the gouge defect caused by the elliptical coil and uncoiling friction. The consequence is the rejection rate dropped to 0%, which was a remarkable improvement.

4. CONCLUSION

1. To decrease the rejection rate of the leaf mark and gouge defects of medium carbon steel SAE 1050, the latent heat is released in the laminar cooling zone in advance by reducing the MT. The FT is also reduced to decrease the temperature difference between the FT and MT that facilitates the MT to the target temperature and improves the formability of the material.
2. The length of the head and tail of the coil during hot-rolling is reduced, and the coiling tension is increased, in addition, the coiling time of the coil hung on the mandrel is increased to enhance the support of the inner ring of the coil after coiling.
3. During the production of TNRL, the line speed is reduced to below 100mpm in the whole process to reduce gouge defects caused by the uncoiling and sliding of the elliptical coil.
4. The rejection rate of the leaf marks of SAE 1050 decreased from 4.83% to 0.25%, reaching the project target (<1.45%), showing a remarkable improvement. (Fig.11)

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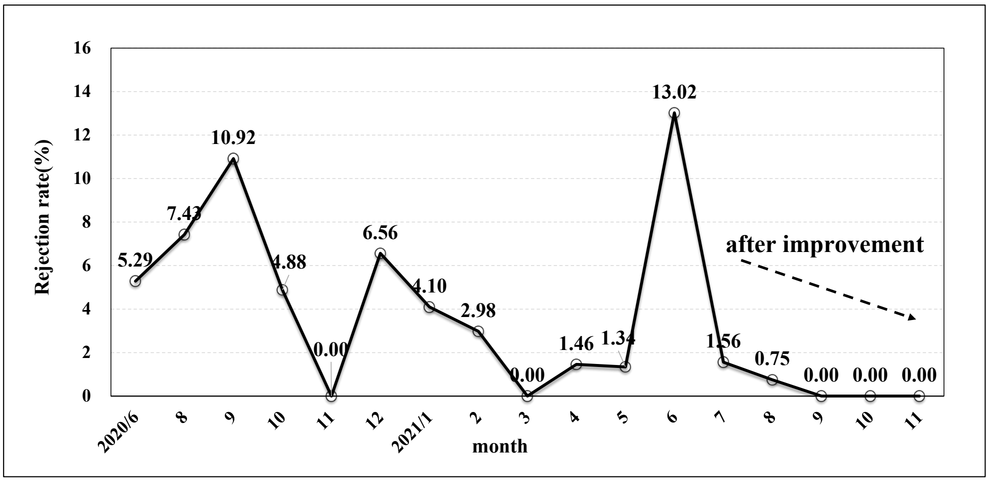

Fig.11. Rejection rate of leaf mark defects after improvement.