Root cause Analysis of Tong mark defect during material handling of IF steel coils

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Abstract

The cold rolled IF coils are usually carried into Batch Annealing Furnace (BAF) for annealing by means of mechanical tongs. On discharge of coils from BAF, a peculiar type of line marks (surface defect) are appeared perpendicular to rolling direction on both inner and outer wraps of IF steel coils. These defects are causing significant appearance problems after painting. In the present work, the morphology of the defect was examined in detail through characterization by visual inspection and optical microscopy. Surface topography and residual stress analysis along with Finite element simulation was also performed to understand the mechanism behind the origin of this line marks. From the study, it is clear that the curvature mismatch between coil and tong give rise to the origin of this defect.

Key words: Tong Mark, batch annealing furnace, Interstitial Free steel

1. INTRODUCTION

Interstitial-Free (IF) steels are widely used in automotive industry as body skin panel, which demands defect free surfaces. These are produced by cold rolling followed by annealing to improve steel strip formability and to reduce residual internal stresses imparted during rolling. These coils are heated and held at a temperature of 700°C inside Batch Anneal Furnace (BAF), and then cooled before unloading. After annealing, the coils are further processed by skin pass mill to get uniform thickness (Fig.1). Skin-pass rolling is given to get the desired surface roughness and to suppress yield point elongation (stretcher strain) by giving some elongation to the strip. The line marks like defect was absorbed after the annealing process. It was also observed that the severity of tong mark is high for softer grades.
Tong marks were classified under sticker defects by Peter et al. [1]. Stickers are produced by the pressure welding of bare metal surfaces. It has not yet been decisively established whether this welding is caused by diffusion welding processes between two surfaces, sintering processes or other adhesion mechanisms. However, a number of different types of stickers have been observed. In some cases, the processes which create these defects have been identified. The causes of these welding phenomena were comprehensively investigated for the first time by Pawelski et al. [2]. Steel grade, strip profile, coiling tension, steel cleanliness, strip properties (roughness, topography and dimensions) and coil dimensions are the various parameters contributing stickers. Ma et al. [3] presented an experimental investigation of surface transfer in cold rolling of carbon steel strip and the influence of rolling parameters.

In the present work, the tong mark defects were analyzed in more detail and metallographic studies were done at both defect and normal regions of steel surface to find the root cause of the problem. Finite element analysis along with residual stress and surface roughness measurement has been carried out to find out the mechanism which causes the defect.

2. ROOT CAUSE ANALYSIS

The coils are stacked one above another and covered with a metal closure during annealing. The mechanical tong holds the coil at both inner and outer coil surfaces for lifting as shown in Fig.2. The defects (line marks) are observed after the annealing and are identified to happen always at places where the tongs hold the coil for lifting. Due to Tong mark defects, considerable length (300 meters each side) of steel coils from both the inner diameter (ID) and the outer diameter (OD) portions are scrapped. Metallographic examination of defect surface aids in understanding the origin of defects which in turn helps in designing of preventive measures, to be considered.

**Fig.2 Line Diagram of Mechanical Tong**

2.1 Visual Inspection

The line marks are observed running perpendicular to rolling direction in both inner and outer wraps of coils during inspection. They come in the form of lines or flowery pattern perpendicular to the rolling direction extending from one edge of the strip surface as shown in Fig.3. The pitch of the defect is the circumferential distance of the inner wraps (about 2mts.) and gradually reduces in intensity towards center portion of the coil.

**Fig.3 BAF tong mark defect as seen at Recoiling line**
2.2 Mechanical and chemical properties

The engineering stress-strain plot of the chosen steel grade is shown in fig. 4. Table 1 and 2 reveals the mechanical and chemical properties of IF steel respectively. The lean chemistry of chemical properties of this grade is well reflected as a very soft and ductile material in the mechanical properties.

![Fig.4. Engineering stress strain diagram of IF steel](image)

2.3 3D optical laser spectroscopy

The surface roughness and other surface parameters were measured over an area. The ISO 25178[4] series describes all these roughness parameters values in detail. By a combination of the various parameters, it may be possible to identify surfaces which have undergone plastic deformation at surface asperity level (a relatively flat top and deep valleys). The measurement was made across the defect. The surface parameters were measured at various points in both defect and defect free regions. The total width of the sample is 12 mm and 5 locations were located to do surface analysis.

![Fig.5 Roughness measurement of surface roughness across the defect](image)

* Sq=Root mean square height of the surface, Ssk=Skewness of height distribution, Sku=Kurtosis of height distribution, Sp=Maximum height of peaks, Sv=Maximum height of valleys, Sz=Maximum height of the surface, Sa=Arithmetical mean height of the surface.

A Gaussian surface has a kurtosis value of 3 and skewness of zero which has a symmetrical shape for the surface height distribution. Micro machining and polishing produce surfaces typically have ‘Gaussian type’ distributions. Most of the common machining processes produce surfaces with non-Gaussian distributions. Turning, shaping and electro-discharge machining produce a peaked surface with positive skewness. Grinding, milling, honing and abrasion processes produce grooved surfaces with negative skewness and high kurtosis values.

Table 3 shows the surface parameters measured across the defect. The roughness value at defect portion is low as compared with defect free region. This indicates that a local plastic deformation of surface asperities are happened at the coil-Tong interface and extended inside to the coil for considerable number of wraps from both inner and outer surface of coils. From Table 3 it was found that for defect region and normal region the skewness is nearly similar and close to zero, but kurtosis is varying. Kurtosis parameter is high for normal region. This implicates the defect region is relatively flat top because of the plastic deformation of surface asperities.

2.4 Optical microscopy

Metallographic samples were prepared from both defect and non defect regions. It is found that grain coarsening is taking place at the defect region (Fig.6) whereas the grains are finer and nearly equiaxed at the non-defect regions (Fig.7). The grain coarsening may be due to slow cooling during annealing process. The mechanical tong exerts contact pressure at gripping portion and the surfaces are brought into close proximity. It confirmed that gluing of surfaces is taking place during loading to batch annealing furnace. Because of gluing of surfaces at Tong gripping areas, the convection heat transfer is not taking place at this portion and only the viable heat transfer mode is conduction during annealing. Due to the above fact, H2 + N2 gas flow is restricted at this region causing slow cooling rate and thereby coarsening of grains is taking place.
Table 1 Mechanical properties of IF steel

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
<th>Yield strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Total Elongation (% @ 50mm Gauge length)</th>
<th>Strain hardening exponent (n)</th>
<th>Uniform elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>0.8</td>
<td>132</td>
<td>283</td>
<td>57</td>
<td>0.278</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 2 Chemical composition of IF Steel in Wt %

<table>
<thead>
<tr>
<th></th>
<th>C[%]</th>
<th>Mn[%]</th>
<th>S[%]</th>
<th>P[%]</th>
<th>Si[%]</th>
<th>Al[%]</th>
<th>Ti[%]</th>
<th>Nb[%]</th>
<th>N[ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF Steel</td>
<td>0.0035</td>
<td>0.15</td>
<td>0.012</td>
<td>0.018</td>
<td>0.015</td>
<td>0.060</td>
<td>0.1</td>
<td>0.02</td>
<td>40</td>
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</tbody>
</table>

Table 3 3D surface topography parameters

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Distance across defect,mm</th>
<th>Sq[µm]*</th>
<th>Ssk*</th>
<th>Sku*</th>
<th>Sp[µm]*</th>
<th>Sv[µm]*</th>
<th>Sz[µm]*</th>
<th>Sa[µm]*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1.111</td>
<td>-0.107</td>
<td>7.636</td>
<td>11.644</td>
<td>11.091</td>
<td>22.734</td>
<td>0.799</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0.717</td>
<td>0.138</td>
<td>12.830</td>
<td>9.557</td>
<td>7.431</td>
<td>16.988</td>
<td>0.461</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>0.731</td>
<td>0.058</td>
<td>11.272</td>
<td>8.855</td>
<td>6.728</td>
<td>15.583</td>
<td>0.472</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>0.753</td>
<td>0.033</td>
<td>10.848</td>
<td>7.690</td>
<td>6.759</td>
<td>14.448</td>
<td>0.480</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>0.944</td>
<td>-0.090</td>
<td>6.490</td>
<td>9.897</td>
<td>9.427</td>
<td>19.323</td>
<td>0.679</td>
</tr>
</tbody>
</table>

Fig.6. Defect free region
Fig. 7. Defect Region

- a) Non-defect region
- b) Defect region inner
- c) Defect region outer

Fig. 8. Residual stress measurement
2.5 X-Ray Diffraction (Residual stress)

The surface residual stress is measured by using XRD by sin2ψ technique. The samples were prepared in defect and non defect regions. The measurement (Fig.8) reveals the existence of compressive stresses maximum at the defect center and reduces gradually towards defect free portion which posses tensile residual stress at surface. The presence of compressive residual stresses at the defect region (Fig.5 and 6) evident that considerable amount of plastic deformation is occurred during the interaction between mechanical tongs and coil interface.

2.6 Effect of interface geometry

The clamping action of tongs during coil loading and unloading is simulated by finite element analysis to find the contact pressure distribution in the coil. The finite element analysis is done for different coil diameters. A schematic of the clamping device is shown in Fig.7. The force due to self weight acting on the coil is W, the clamping force is R and the net frictional force between the clamping pads and the surface of the roll is 2μR. The minimum clamping force required to lift the roll is R = (W/2μ). In practice, the clamping force has to be significantly higher to keep the roll secured from dynamic loads also introduced. The tong will exert relatively higher than the required force for safety reasons. The gripping force is applied on the pin on both inner and outer pad. The gripping force is calculated by using the formula, R=Wa/2b (a and b is height and width of main lever as shown in Fig.2).

The coil and the Tong were modeled by finite elements using ABAQUS/implicit [5]. Using appropriate symmetry boundary conditions, only a half of the coil and a half of the clamping pad had been modeled. The finite element mesh along with the loading and boundary conditions used are shown in Fig.9. The mesh of the roll consisted of 10260 eight noded brick elements. The clamp was meshed with 384 eight noded brick elements. Contact conditions were specified at interface between shoes and the coil, coefficient of friction(μ) of 0.1 is used. The gripping force is applied on the pin on both inner and outer pad. For a coil weight of 30 Tons and the gripping force is calculated R= 80774 Kgf . The clamping simulation was done in two steps. First, the clamp is compressed against the roll by applying a prescribed indentation. Second, the clamp was lifting a coil to certain height (gravity loading).

Fig. 10 shows the typical contact pressure distribution on both inner and outer surface of the coil. It was observed that the contact pressure is maximum at where the Tong pad is making line contact and low at other contact place. The pitch of the maximum contact pressure region is exactly same as observed in inspection. The inner shoe radius is 305 mm and outer shoe radius is 900 mm. Coils of three different diameters were analysed against for this shoes. Table 4 shows the contact pressure distribution at inner and outer radius of the coil for different coil diameters.

The table 4 shows the contact pressure distribution at inner and outer radius of the coil for different coil diameters. For the profile 1 (Inner Diameter: 305mm, Outer Diameter: 610mm), the maximum contact pressure is 53 MPa in ID and is 84 MPa at OD. Profile 2 (Inner Diameter:305mm, Out Diameter:900mm), the maximum contact pressure is reduced to 44 MPa in ID and 36MPa in OD. Profile 3 (Inner Diameter:305mm, Outer Diameter: 1100mm), the maximum contact pressure is 29 MPa in ID and 44MPa in OD. From the result, it was concluded that while the pad radius of curvature is matches with coil curvature, the contact pressure is minimum. Otherwise the tong exerts high contact pressure only at particular area of coil, (like line contact) which creates an impression on coil.

Table 4 Contact pressure between wraps of coil during handling

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Interface profiles</th>
<th>Contact pressure, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner Region</td>
</tr>
<tr>
<td>1</td>
<td>Coil radius&lt; Tong radius</td>
<td>53</td>
</tr>
<tr>
<td>2</td>
<td>Coil radius= Tong radius</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>Coil radius&gt; Tong radius</td>
<td>29</td>
</tr>
</tbody>
</table>
Fig. 9 Finite Element model and Loading and boundary conditions

Fig. 10 Typical contact pressure distribution
4. CONCLUSIONS

From metallographic studies and the surface roughness and residual stress analysis, it was found that local plastic deformation of surface asperities is taking place for steel sheet wraps. The interface geometry of coil and lifting pad is important which affects the plastic deformation of surface asperities.

It was observed from the metallographic and surface analysis that the curvature mismatch between coil and tong profile was the major cause of the defect. The tong exerts high contact pressure only at particular area of coil, (like line contact) which creates an impression on coil. Recommendations were suggested to use different diametric pads for each diameter range of coils. This could reduce the Tong mark severity level.

REFERENCES


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