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Research Article

Research on Stress Neutral Layer Offset in the Straightening Process

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The stress neutral layer offset is analyzed by theoretical and numerical calculation methods. In traditional straightening theory, the stress neutral layer was consistent with the geometric central layer. However, there is a phenomenon that the stress neutral layer has some offset with the geometric neutral layer. This offset is a very important factor for improving the precision of the straightening force. The formula of the stress neutral layer offset is obtained by a theoretical method and the change law is given by numerical calculation method. The neutral layer offset theory provides the theoretical basis for establishing the model of straightening force precisely.

1. Introduction

In the straightening process, there are some factors which influence the straightening precision. The plate quality is determined by the straightening precision. So the straightening precision is a very important factor for the product. In the traditional straightening theory, the stress neutral layer was considered consistent with the geometric central layer. On this assumption, researchers studied the influence factors to straightening precision, such as the mechanics parameters, the straightening force, and the bending modulus. Roller-bending device and technology were studied by Zhou [1, 2]. He analyzed the distribution of the residual stress in the straightening process [3]. Unequal-roller-distance straightening was optimized and simulated by Jing and Dou [4]. Angle beam straightening procedure was simulated using the FEM by Sun et al. [5].

In order to obtain the better straightening results for the deformed steel plate, the change law of stress and strain must be researched in the bending process [6]. At present, the traditional straightening model did not consider the stress neutral layer offset which influenced the straightening precision. So if the straightening precision is to be improved, the neutral layer offset must be analyzed [7].

In this paper, according to the plate bending theory, the neutral layer offset is analyzed. The formula for the neutral layer offset is obtained. The numerical analysis also gives the change law of the neutral layer offset. Finally, it is used to reestablish the straightening model. This research can provide a theoretical basis to improve the straightening precision.

2. Theoretical Analysis of Stress Neutral Layer Offset in the Plate Bending

In order to simplify the model, there are some assumptions [8, 9].

(1) Planar Cross Section Assumption. The cross section of steel plate still keeps a plane after the plastic deformation.

(2) Volume Invariance Assumption. The volume of the object is invariant before and after the plastic deformation.

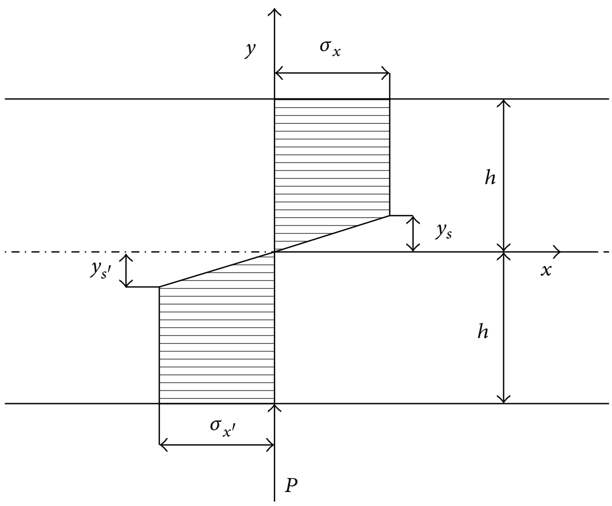

FIGURE 1: The traditional stress diagram in the cross section.

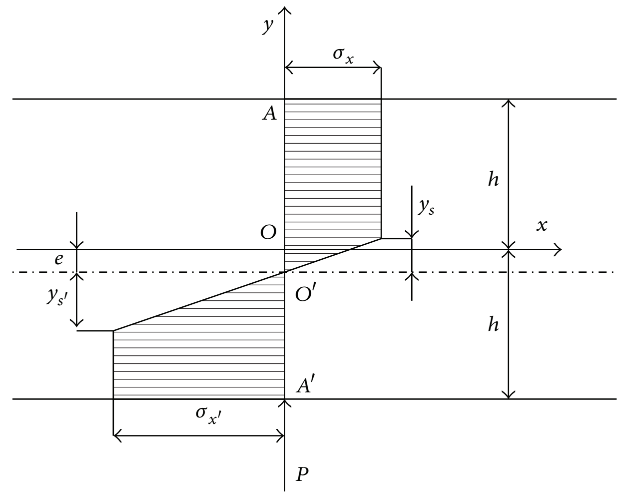

FIGURE 2: The new stress diagram in the cross section.

(3) Plane Strain Assumption. The deformation of the plate along the width direction is neglected. The deformation zone is in a plane strain state.

An ideal elastic-plastic material is used to analyze the offset of stress neutral layer in the plate bending. Figure 1 shows the stress diagram. It is the stress diagram in the cross section without the neutral layer offset. The stress diagram in the cross section is shown in Figure 2, which is considering the neutral layer offset. In the elastic deformation region, the relationship between stress and strain satisfied Hooke's law; namely, $\sigma = E\varepsilon$; in the plastic deformation region, the relationship between stress and strain is $\sigma_s = E\varepsilon_s$.

In Figure 2, the geometrical central layer is the x-axis and the neutral axis is the y-axis in the Cartesian coordinate system. The imaginary line parallel to the y-axis is the stress neutral layer. The height of cross section is 2 h; the uniform load is P. The elastic region, respectively, in upper and lower stress neutral layer is y_s and $y_{s'}$. e denotes the neutral layer offset in Figure 2.

The plate follows the Von Mises plastic yield criterion:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_s^2 = 6k^2, \quad (1)$$

where k is the shear yield limit and $k = (1/\sqrt{3})\sigma_s$.

According to the planar cross section assumption (generally taking $\sigma_1 > \sigma_2 > \sigma_3$), there is

$$\sigma_2 = \sigma_m = \frac{(\sigma_1 + \sigma_3)}{2}. \quad (2)$$

So the Von Mises plastic yield criterion can be written as

$$\sigma_1 - \sigma_3 = \frac{2}{\sqrt{3}}\sigma_s. \quad (3)$$

By analyzing the loaded plate in the straightening model, it is known that the stress state of the point A on the upper surface is $\sigma_x = \sigma_x$, $\sigma_y = 0$, and $\tau_{xy} = 0$. In the plane strain state, it is also known from the incremental theory that $\tau_{zx} = \tau_{zy} = 0$. Combining formula (2) with formula (3), $\sigma_1 = \sigma_x$, $\sigma_2 = (1/2)(\sigma_1 + \sigma_3)$, and $\sigma_3 = 0$ can be obtained where $\sigma_x = (2/\sqrt{3})\sigma_s$.

Using the same method, the stress state of the point A' on the lower surface can be obtained:

$$\sigma_1 = \sigma_{x'},$$
$$\sigma_2 = \frac{1}{2}(\sigma_1 + \sigma_3), \quad (4)$$
$$\sigma_3 = \overline{p},$$

where $\sigma_{x'} = (2/\sqrt{3})\sigma_s + \overline{p}$.

At the cross-section AA', take the unit length in the z direction. It is an equilibrium condition of force along the x direction. It can be obtained from $\sum F_x = 0$ that

$$\sigma_x (h - y_s) + \frac{1}{2}\sigma_x (y_s + e) = \sigma_{x'} (h - y_{s'} - e) + \frac{1}{2}\sigma_{x'} y_{s'}. \quad (5)$$

The formula of the neutral layer offset can be obtained as

$$e = \frac{n-1}{n+1}h + \frac{1}{2}(1-n) y_s, \quad (6)$$

where $y_s/y_{s'} = \sigma_s/\sigma_{s'} = n$ is called the elastic ratio.

From formula (6), it is known that the stress neutral layer offset can be obtained when the elastic ratio is given.

3. Simulation of the Stress Neutral Layer Offset by FEM

The finite element model is shown schematically as in Figure 3. The parameters of the straightener are shown in Tables 1 and 2. Taking the time when the upper straightening roll is pressed completely to analyze the plastic deformation of the place where the straightening force is loaded. The force loaded on the straightening roll is 150 t.

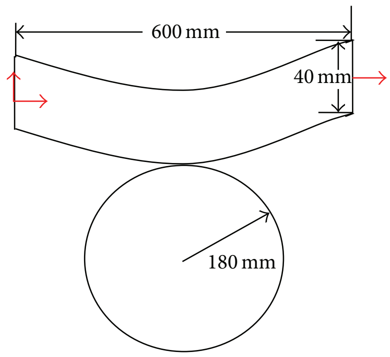

FIGURE 3: Finite element model.

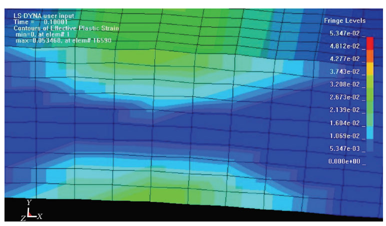

FIGURE 4: The cloud chart of the effective plastic strain.

TABLE 1: Basic information about plate.

Plate thickness/mm	40
Plate width/mm	400
Plate length/mm	600
Elastic modulus/GPa	117
Poisson ratio	0.2
Yield limit/MPa	400

TABLE 2: Basic information about straightening roll.

Diameter/mm	180
Barrel length/mm	900
Roller spacing/mm	40
Elastic modulus/GPa	210
Poisson ratio	0.3
Dynamic friction coefficient	0.25
Static friction coefficient	0.35

Figure 4 is the cloud chart of the effective plastic strain. From this figure, we know that the maximum plastic strain is not in the contact point between the roller and the plate. The maximum occurred in the left of the neutral axis. This is because of the different constraint conditions in the left boundary and the right boundary. The elastic region is not symmetric in the tensile region and the compressive region, namely, the neutral layer, is offset.

Taking $x = -0.05$ m and $x = 0.03$ m, the stress in the X direction is analyzed in Figure 5. From this figure, we know that there is the neutral layer offset in the regions $[-0.04, 0.04]$ and in other region there is only elastic deformation because the stress does not reach the yield limit.

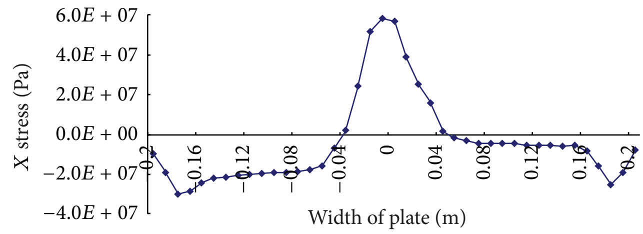

FIGURE 5: The X stress in width of plate.

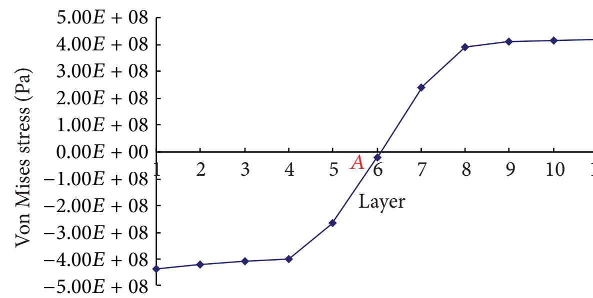

FIGURE 6: The Von Mises stress in the cross section.

The cross section of the straightening plate is divided into 10 layers. The Von Mises stress of every layer is analyzed which is shown in Figure 6. From the figure, we know that the Von Mises stress is not equal to zero in the geometrical central layer. It also shows that the stress neutral layer is above the geometrical central layer.

4. Conclusion

In this paper, the stress neutral layer offset was analyzed by theoretical method and the numerical methods. From the theoretical analysis, we know that the stress neutral layer offset will appear when the plate is in plastic bending. From the numerical analysis, we know the changing law of the stress neutral layer offset. It is a very important factor for ensuring the accurate straightening force. The theoretical results and the numerical results have the same change law of the stress neutral layer offset. This research can provide the theoretic basis for establishing a more precision straightening force model.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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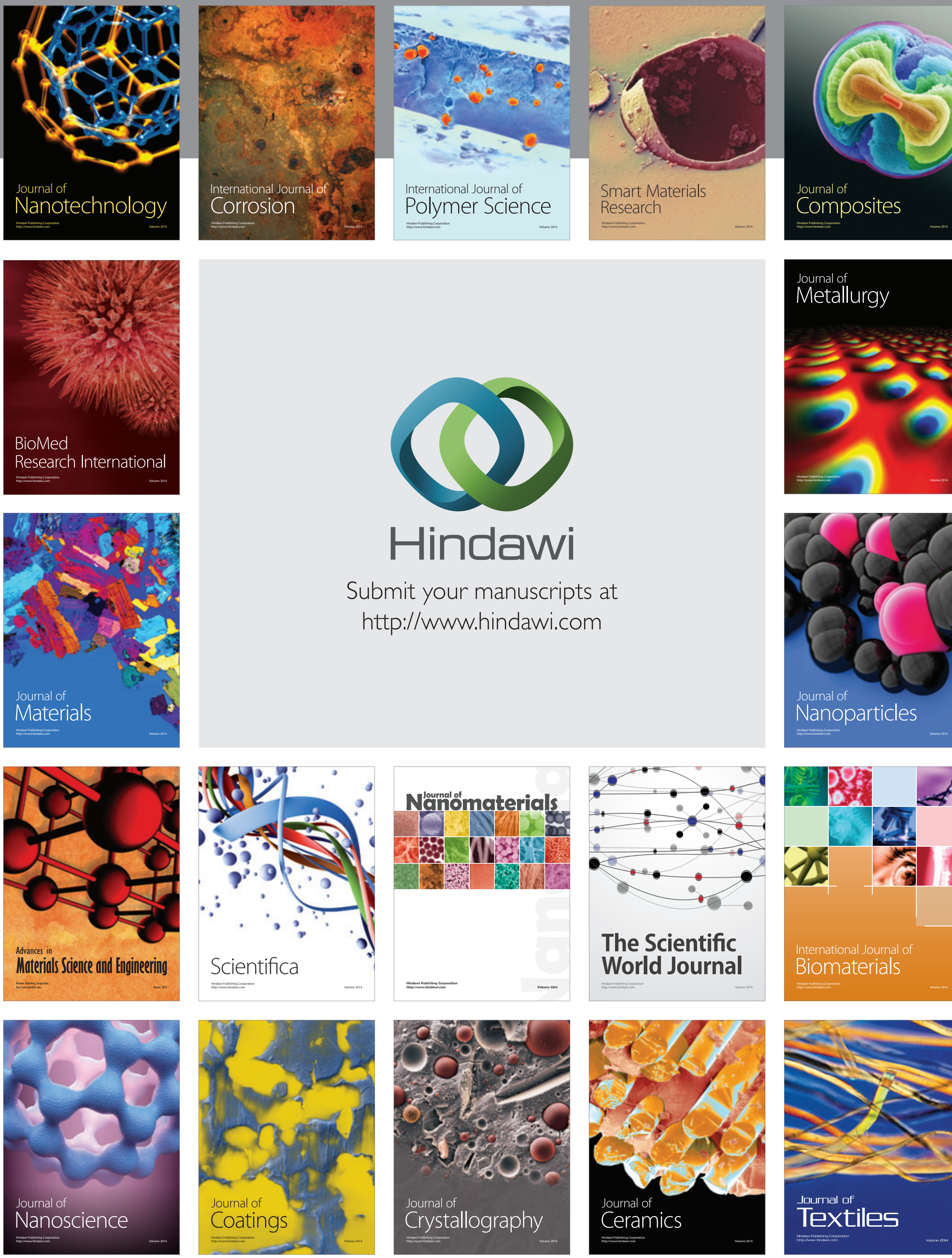
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