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Analysis of the neutral layer offset of bimetal composite plate in the straightening process using boundary element subfield method

H.L. Gui[a,b,*], L.F. Ma[a,c], X.G. Wang[a,b], X. Yang[a,c], Q.X. Huang[a,b], Q. Li[d]

[a] Heavy Industry Engineering Center of China Ministry of Education, Taiyuan University of Science and Technology, Taiyuan 030024, PR China
[b] Material Science and Engineering Science College, Taiyuan University of Science and Technology, Taiyuan 030024, PR China
[c] College of Mechanical Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, PR China
[d] Technology Center, Taiyuan Heavy Industry Co. Ltd., Taiyuan 030024, PR China

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ABSTRACT

In the classical straightening theory, it supposes that the geometric central layer and stress neutral layer are a coincidence. However, there is some offset in fact. This is one of the reasons why straightening force is inaccurate in the straightening process. In this paper, the boundary element subfield method is used to analyze the three-dimension elastic–plastic deformation of a bimetal composite plate in the straightening process. At first, the boundary integral equation of a bimetal composite plate is established by the boundary element subfield method. Then, through analyzing the deformation in the rolled piece straightening, it shows that the geometric central layer does not coincide with the neutral layer. The formula of the neutral layer offset is established and the change law is discussed. At the same time, the influence of the neutral layer offset on the precision of straightening force is researched. From the numerical analysis, it shows that the error of the straightening force reaches to 5% whether considering the neutral layer offset. This demonstrates that the neutral layer offset is one of the important factors to give the straightening force inaccurately. It is ought to consider the neutral layer offset when the model of straightening force is established.

1. Introduction

A bimetal composite plate is produced by some methods such as the rolling composite, the explosive composite and the casting composite. The microstructure and properties of the metal composite plate have improved. The bimetal composite plate is mainly researched in the composite technology and the rolling technology. Wang and co-workers [1] introduced the advantages and disadvantages of the research trend, the classification and the technology about the bimetal composite plate. The new technologies and the application prospect of bimetal composition plate were posed emphatically in the casting field. Pan et al. [2] and Tian et al. [3] described the composite technology of the metal composition material and its advantages and disadvantages. The new manufacture technologies were introduced as an efficiency, low consumption and short technological process; Sun and Liu [4] simulated the rolling process of the bimetal composite plate using the

* Corresponding author at: Material Science and Engineering Science College, Taiyuan University of Science and Technology, Taiyuan 030024, P.R. China.
E-mail address: guihailian@qq.com (H.L. Gui).

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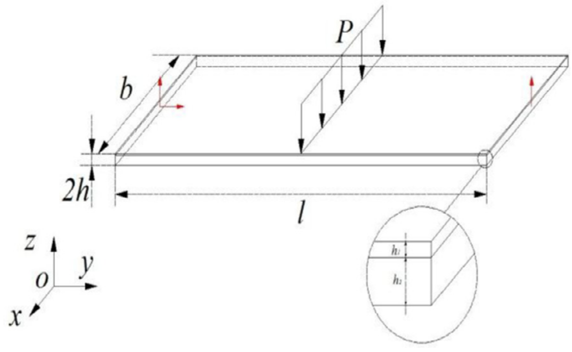

Fig. 1. Force diagram of bimetal composite plate.

finite element method (FEM) and obtained the distribution of the rolling force. Tian [5] established a plastic deformation model of the bimetal composite plate and analyzed the composition rolling and technologies. Duan et al. [6] studied the deformation merits of the bimetal composition rolling and made sure the relationship between forward slip and rolling speed. The changed law was obtained in the asymmetric rolling. Zong et al. [7] analyzed the reversing rolling of the bimetal composition plate and determined the joint bonding strength.

It is worth pointing out that most of the above studies only considered the productive process. However, there are some shape defects of the bimetal composition plate and these defects must be straightened to become qualified products. So researching the straightening process is very important for qualified products. The straightening theory of the metal composition plate comes from the traditional straightening theory of the plate. But because of the merits of the metal composition, the traditional straightening technologies must be improved. There are not coordinated consistent between the geometric center layer and the neutral layer because of the different yield limits. The neutral layer offset must be considered when the straightening force model is established. The report of this respect only can be found in Ref. [8].

On the other hand, the straightening process of the bimetal composition plate is simulated by FEM. The FEM have some limits in the binding surface and the grid layout. These may be influence the calculation accuracy. The boundary element method (BEM) has been applied successfully to solve the thin plate bending problem since the 1970s [9]. According to the Rayleigh–Green identity, the biharmonic governing equation of the thin plate can be written as the boundary integral equation (BIE) with four boundary variables. A direct approach is employed to obtain a general formulation of plate bending problems in terms of a pair of singular integral equations involving displacement, normal slope, bending moment and shear on the plate boundary [10]. Hu and Liu [11] solved the thin plate bending problem with the fast multipole boundary element method. Chen and co-workers [12] used an efficient non-linear coordinate transformation to deal with the troublesome nearly singular integrals arising in the BEM formulation for thin structures. In other paper, Chen and co-workers [13] presented a fast multipole accelerated singular boundary method (SBM) to the solution of the large-scale three-dimensional Helmholtz equation at low frequency. A three-step solution technique is presented for solving nonhomogeneous problems using the multi-domain boundary element method [14].

In this paper, using the boundary element subfield, the bimetal composition plate is considered as two regions through the binding surface. The boundary integral equations are established in each region and the relationship between two regions is established by the nodes of the binding surface. At last, solving the equation, the displacement and force can be obtained. The deformation of the bimetal composite plate is discussed and the changed law of the neutral layer offset in cross section can be analyzed. From different straightening forces, the formula of the neutral layer offset is obtained. The straightening force model which considered the neutral layer offset is applied to control the straightening process in the hydraulic 11roll straightening machine.

2. The boundary integral equation of the thin plate bending problem

The bimetal composite plate can be considered as a plane stress problem. The simple sketch map of the bimetal composite plate shows as Fig. 1. Specifically, the plate is modeled by a region Ω with boundary Γ. The thickness of plate is $2h$, the width of plate is b, and the length of plate is l. In the left boundary, there are boundary restraints in Y axis and Z axis, namely $v=0$, $w=0$. In the right boundary, there is boundary restraint in Z axis, namely $w=0$.

2.1. The governing equation of the bimetal composite plate

In the model, the bimetal composite plate is loaded by a transverse load intensity q defined on Ω. The deflection w is governed by the differential equation [18]

$$D\nabla^4 w = D\nabla^2\nabla^2 w \equiv D[\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4}] = q \tag{1}$$