



Modeling deformation resistance for hot rolling based on generalized additive model

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ARTICLE INFO

Key words:

Hot rolling

Deformation resistance

Mathematical model

Generalized additive model

ABSTRACT

A model of deformation resistance during hot strip rolling was established based on generalized additive model. Firstly, a data modeling method based on generalized additive model was given. It included the selection of dependent variable and independent variables of the model, the link function of dependent variable and smoothing functional form of each independent variable, estimating process of the link function and smooth functions, and the last model modification. Then, the practical modeling test was carried out based on a large amount of hot rolling process data. An integrated variable was proposed to reflect the effects of different chemical compositions such as carbon, silicon, manganese, nickel, chromium, niobium, etc. The integrated chemical composition, strain, strain rate and rolling temperature were selected as independent variables and the cubic spline as the smooth function for them. The modeling process of deformation resistance was realized by SAS software, and the influence curves of the independent variables on deformation resistance were obtained by local scoring algorithm. Some interesting phenomena were found, for example, there is a critical value of strain rate, and the deformation resistance increases before this value and then decreases. The results confirm that the new model has higher prediction accuracy than traditional ones and is suitable for carbon steel, microalloyed steel, alloyed steel and other steel grades.

1. Introduction

Deformation resistance is an important parameter which affects the rolling force during hot strip rolling process. It plays a crucial role in the reasonable determination of rolling process parameters and safe operation of mill equipment. The model of deformation resistance is the core of the rolling force model^[1,2], and its prediction accuracy directly affects the accuracy of the mathematical model for whole rolling process and the final thickness of finished strip product^[3]. Deformation resistance is not only related to strain, strain rate and rolling temperature, but also affected by the chemical composition and microstructure of the rolled material, and the influence relationship is very complicated. At present, there are two main modeling methods for deformation resistance; one is the analytic method, and the other is artificial neural network^[4,5]. The

analytic method is adopted in most of current online deformation resistance models, which includes two main categories. One is to mechanically consider the effects of strain, strain rate and rolling temperature, and the other is to consider the effects of recovery and recrystallization^[6]. Most of traditional analytical models are designed to fit the data from Gleeble thermo-mechanical simulation test^[7,8]. These models mainly aim at the specific steel grade and have some limitations in application. For example, there are some differences between Gleeble test and real hot rolling process^[3]. In fact, the field L2 data contain a lot of information, and the deformation resistance model based on the field measured data is more suitable for the actual hot rolling process^[4]. In addition, artificial neural network has gradually been used to study the deformation resistance in recent years^[9,10]. However, the obtained models are black box models, which are difficult to

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analyze the influence of different factors on the deformation resistance.

In this work, a new model of deformation resistance was proposed based on generalized additive model. The practical modeling test was carried out in use of a great deal of hot rolling process data. The quantitative effects of strain, strain rate and rolling temperature on deformation resistance were obtained. The practical modeling results show that the built model has good prediction accuracy and is suitable for carbon steel, microalloyed steel, alloyed steel and other steel grades.

2. Modeling Method Based on Generalized Additive Model

2.1. Generalized additive model

With the development of regression analysis, the non-parametric regression is put forward. It does not require a model to satisfy the linearity assumption, and it can flexibly detect the complex relationship between the data. The non-parametric regression has been widely studied and applied owing to its advantages such as the freedom of regression function form, few constraints, strong adaptability, and so on^[11]. However, the estimation error will be increased and the curse of dimensionality can be aroused when the number of independent variables in the model is large. In addition, it is difficult to explain the relationship between the independent variables and dependent variable in non-parametric regression based on estimation of kernel and smoothing spline. The additive model was proposed by Stone in 1985^[12], and each additive term in the model is estimated by a single smooth function, which can explain how the dependent variable changes with the independent variable in each additive term. In 1986, Hastie and Tibshirani extended the application of the additive model and proposed the generalized additive model (GAM)^[13]. Its expression is listed as follows:

$$g(\mu) = \alpha + \sum_{j=1}^p f_j(X_j) \quad (1)$$

where, $g(\cdot)$ is the link function; $\mu = (Y|X_1, X_2, \dots, X_p)$; α is the intercept and $f_j(X_j)$ is an arbitrary single variable function of X_j . In this model, the distribution of the dependent variable can be not only the normal distribution, but also the binomial distribution, chi square distribution, and so on. The GAM has fewer requirements on samples, and it has a very wide range of applications.

The advantage of GAM is that it can deal with the nonlinear relationship between the dependent variable and the independent variables in the high dimensional data, which is suitable for the exploratory analysis of the data or the existence of the dependent rela-

tionship between the response variable and the independent variables. The GAM has been widely used in many fields for data analysis owing to its advantages, such as simple structure, good flexibility, low dimension, easy calculation, good stability, and so on^[14–17].

2.2. Modeling steps

In this work, a data modeling method based on generalized additive model is proposed, which can be applied in many modeling problems. It includes the following five modeling steps and the flow diagram is indicated in Fig. 1:

(1) Pre-analysis of the variables

According to the research purpose, the process data of deformation resistance of hot rolled strip are analyzed. The deformation resistance is selected as the dependent variable of the model, and the contents of chemical element including carbon, silicon, manganese, nickel, chromium, niobium, titanium, and molybdenum, as well as the strain, strain rate, and rolling temperature are selected as the independent variables of the model.

(2) Setting of the model

The general form of the GAM is obtained by the dependent variable and the independent variables which are selected by step (1).

According to the distribution characteristics of the dependent variable, a certain function is selected as the link function to establish a GAM. The basic idea of the GAM is to introduce a link function which is about the mathematical expectation of the dependent variable, and the effects of the independent variables are accumulative based on this link function. For the deformation resistance of dependent variable, the logarithm function can be used as the link function to build the model.

Subsequently, the smoothing functional form of each independent variable is determined according to the scatter plot and combined with evaluation indexes. In view of the fact that the cubic smoothing spline function has the advantages of simple calculation, good stability, and guaranteed convergence, the independent variables of non-parameter part are fitted by this spline function.

(3) Estimation of the model

Once the model form is determined, all the parameters in the model can be estimated according to the sample data. The estimation of GAM includes the estimation of the link function and the estimation of single variable function for each independent variable. The estimation of the GAM is to minimize the difference between the desired value and the observed value by the local-scoring procedure. It is combined with the iteratively reweighted least square (IRLS) and the back-fitting algorithm. After the model

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