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# Mathematical model of deformation resistance of 30MnSiV steel①

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**[Abstract]** Based on 30MnSiV steel, the deformation resistance was studied by using Gleeble-1500 thermomechanical simulator. The mathematical model of the deformation resistance is established by analyzing the relationship of the deformation temperature, deformation rate and deformation resistance. The regression equation is highly noticeable by means of regression analysis. The mathematical model corresponds to test data by means of the contrast.

**[Key words]** thermomechanical simulator; mathematical model; regression; deformation resistance
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## 1 INTRODUCTION

Metal-plastic deformation resistance is one of the basic parameter of rolling process and equipment parameter[1, 2]. The effect of the deformation conditions on deformation resistance is difficult to count and analyze by means of theoretical method because the metal plastic flow is complex. Especially in aspects of high-temperature and high speed, the theoretical research of deformation resistance is very difficult. Deformation resistance of 30MnSiV steel is studied with the help of testing method. 30MnSiV steel is applied to PC steel bar, therefore the force and energy of PC steel bar that is counted have realistic signification by means of the mathematical model of deformation resistance in PC steel bar process. The 30MnSiV steel is tested by Gleeble-1500 thermomechanical simulator. The mathematical model of deformation resistance is established by analyzing the effect of deformation temperature, deformation rate and deformation degree on the deformation resistance.

## 2 TEST CONDITIONS

30MnSiV steel was tested by Gleeble-1500 thermomechanical simulator. The gauge of the test specimen was $d(8 \pm 0.025)$ mm × $(15 \pm 1.0)$ mm. The 30MnSiV wire of $d$10 mm was produced by a high-speed wire CO LTD. The chemical composition of 30MnSiV was listed in Table 1.

**Table 1** Chemical composition of 30MnSiV steel (%)

| C | Mn | Si | V | S | P |
|---|---|---|---|---|---|
| 0.33 | 1.33 | 0.69 | 0.06 | 0.018 | 0.026 |

## 3 TEST DATA ANALYSES

The 100 samples were tested by Gleeble-1500 at different temperatures, rates and degrees. The data were accurate and the testing equipment was reliable. The analysis was as follows[3, 4].

### 3.1 Influence of deformation temperature

The deformation resistance of the steel decreases with increasing the temperature as shown in Fig. 1. The relationship is a power function:

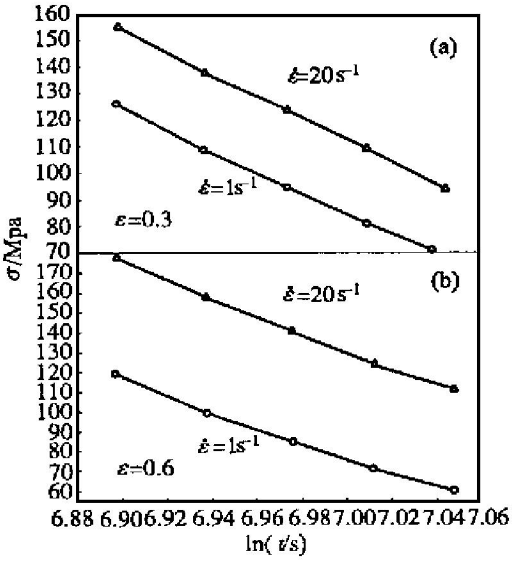


**Fig. 1** Deformation resistance and ln$t$ of 30MnSiV steel
(a) —ε= 0.3; (b) —ε= 0.6

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$$\sigma = A \cdot \exp(Bt) \qquad (1)$$

where $A$ and $B$ are relation coefficients of the steel. The curve of deformation resistance vs ln$t$ to the base $E$ is a liner relationship.

### 3.2 Influence of deformation degree

The effect of deformation degree is fairly big on the process of deformation. The relationship is illustrated in Fig. 2.

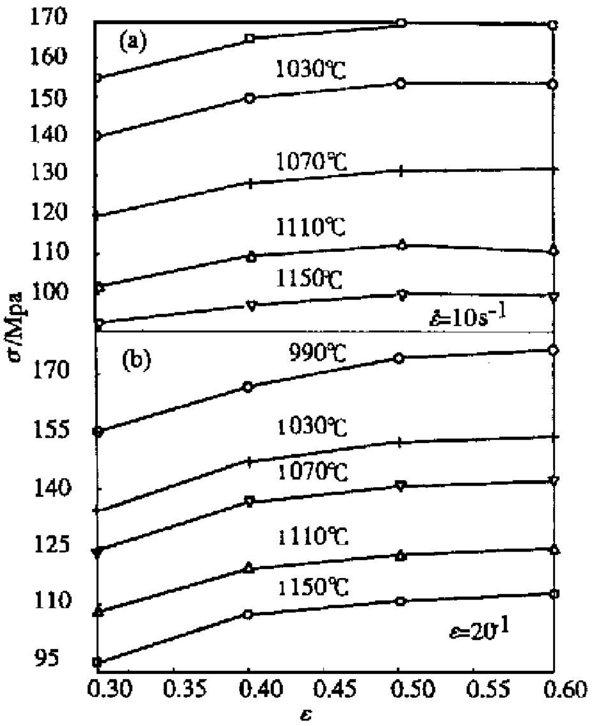


**Fig. 2** Deformation resistance and deformation degree of 30MnSiV steel
(a) —Deformation rate is $10s^{-1}$;
(b) —Deformation rate is $20s^{-1}$

1) Fig. 2 shows that deformation resistance decreases when temperature rises under the same deformation degrees base, nevertheless as a result of the deformation strengthening effect. The deformation resistance rises when deformation degree increases at the same temperature. The relationship is a complex power function.

2) The deformation resistance raises when deformation rate increases to a certain extent.

3) After deformation resistance is maximum (deformation strengthening effect is utmost), the deformation resistance decreases with the increase of deformation degree.

4) The smaller deformation the resistance, the higher the deformation temperature to a related low deformation degree; the greater the action of strengthening effect on deformation resistance.

The relationship between deformation resistance and degree is a complex power function:

$$\sigma = C(\varepsilon^D - \varepsilon) + E \qquad (2)$$

where $C$, $D$ and $E$ are relation coefficients of the steel.

### 3.3 Influence of deformation rate

The analysis shows that the deformation rate influences the deformation resistance not only in chemical composition but also in deformation degree and deformation temperature, as shown in Fig. 3.

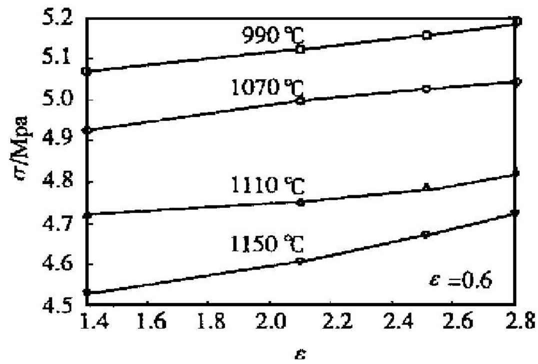


**Fig. 3** Deformation rate and deformation resistance of 30MnSiV

1) On a deformation degree base, the log of deformation resistance to the base $E$ rises along with deformation rate increase and that curve is linear.

2) Effect index of deformation rate is slope ($m$) of the curve of Fig. 3. The curve is shown in Fig. 4. The greater the slope, the higher the deformation temperature.

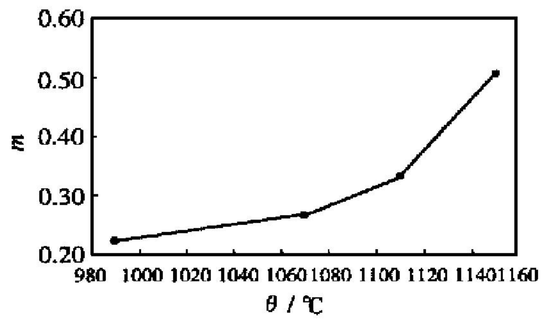


**Fig. 4** Slope of deformation temperature

The relationship between deformation rate and deformation degree is expressed as

$$\ln\left(\frac{\sigma}{\sigma_0}\right) = M \ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right) \qquad (3)$$

where $\sigma_0$ and $\dot{\varepsilon}_0$ are separately standard deformation resistance and rate.

## 4 MATHEMATICAL MODEL OF DEFORMATION RESISTANCE

By the way of analyzing the effect of above-mentioned factor on deformation resistance and comparing different mathematical models[5, 6] of deformation resistance, the model is expressed as

$$\sigma = \sigma_0 X_T X_{\dot{\varepsilon}} X_{\varepsilon} \qquad (4)$$

where

$$X_T = \exp(a_1 + a_2 T)$$

$$X_{\dot{\varepsilon}} = \left(\frac{\dot{\varepsilon}}{10}\right)^{a_3 T + a_4}$$

$$X_{\varepsilon} = a_6\left(\frac{\varepsilon}{0.4}\right)^{a_5} - (a_6 - 1)\left(\frac{\varepsilon}{0.4}\right)$$

$$T = \left(\frac{\theta + 273}{1000}\right)$$

$\sigma_0$ is standard deformation resistance. Its value is 161.125 MPa when $\theta$ is 1 000 ℃, $\varepsilon$ is 0.4 and $\dot{\varepsilon}$ is $10\,s^{-1}$. $\theta$ is deformation temperature, ℃. $\varepsilon$ is deformation degree and $\dot{\varepsilon}$ is deformation rate. $a_1 \sim a_6$ are regression coefficients.

The formula of 30MnSiV steel deformation resistance is regressed by means of MARQUARDT method[7, 8]. Then the regression equation is expressed as

$$\sigma = 161.125\exp(3.0157 - 0.003034 t) \cdot \left(\frac{\dot{\varepsilon}}{10}\right)^{0.000271 t - 0.168}\left[1.508\left(\frac{\varepsilon}{0.4}\right)^{0.389} - 0.508\left(\frac{\varepsilon}{0.4}\right)\right] \quad (5)$$

## 5 ANALYSES

### 5.1 Noticeable test of regression equation

When the regression equation is tested by $F$ test[9] on the noticeable level $\alpha$ which is 0.001, $F$= 377.961> $F^{3,96}_{0.001}$= 5.942. The regression equation is proved to be highly noticeable, meanwhile the $R$ of relation coefficient is 0.98 and shows that the regression equation corresponds to the curve of deformation resistance.

### 5.2 Precision of regression equation

The surplus standard-deviation[10] is

$$S_y = \sqrt{\frac{Q}{N - M}} = \sqrt{\frac{3618.799}{100 - 6}} = 6.20466 \quad (6)$$

where $Q$ is square remnant deviation; $N$ is 100 test data; $M$ is number of regression coefficient. The testing level $\beta$ is 0.05. The $t^{94}_{0.05}$ is 1.9887 by looking over "$t$" distributing table, then $t^{94}_{0.05} \times S_y$ = 12.3 MPa. The forecast precision of regression equation is ±12.34 MPa. The regression equation has possibility of 95% when the deformation resistance is $\bar{\sigma} - 12.34 < \sigma < \bar{\sigma} + 12.34$.

### 5.3 Contrast

The deformation resistance is calculated by Eqn. (5) and contrasts with test data. The contrast result is shown in Fig. 5. The deformation resistance calculated corresponds to test data.

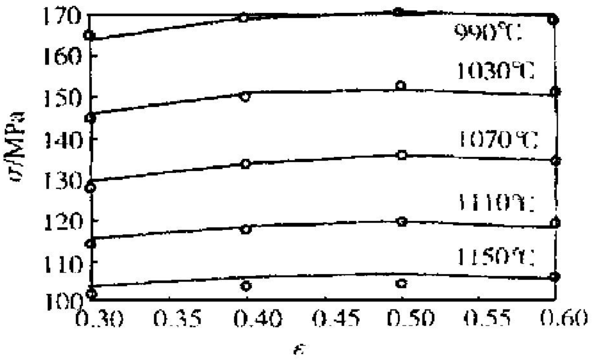


**Fig. 5** Contrast of forecast and test data

## 6 CONCLUSIONS

1) On the base of test data, the mathematical model of deformation resistance is established by analyzing the relationship between deformation resistance and deformation temperature, deformation degree and deformation rate.

2) The mathematical model is highly noticeable by "$F$" test; and calculated deformation resistance corresponds to test data. the result shows that forecast precision of regression equation is fairly accurate.

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