The Flow Behavior Modeling of As-extruded 3Cr20Ni10W2 Austenitic Heat-resistant Alloy at Elevated Temperatures Considering the Effect of Strain

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In order to investigate the compressive deformation behavior of 3Cr20Ni10W2 alloy, a series of isothermal upsetting experiments were carried out in the temperature range of 1203-1403 K and strain rate range of 0.01-10 s⁻¹ on a Gleeble-1500 thermo-mechanical simulator. The results indicate that the flow stress initially increases to a peak value and then decreases gradually to a steady state. The characteristics of the curves are determined by the interaction of work hardening (WH), dynamic recovery (DRV) and dynamic recrystallization (DRX). The flow stress decreases with increasing temperature and decreasing strain rate. The relationship between microstructure and processing parameters is discussed to give an insight into the hot deformation behavior of 3Cr20Ni10W2 alloy. Then, by regression analysis for constitutive equation, material constants (n, α, β, A and Q) were calculated for the peak stress. Further, the constitutive equation along the flow curve was developed by utilizing an eighth order polynomial of strain for variable coefficients (including n, α, A and Q). The validity of the developed constitutive equation incorporating the influence of strain was verified through comparing the experimental and predicted data by using standard statistical parameters such as correlation coefficient (R) and average absolute relative error (AARE) that are 0.995 and 4.08% respectively.

Keywords: 3Cr20Ni10W2 austenitic heat-resistant alloy, flow stress, Constitutive equation, material constants, microstructure evolution

1. Introduction

3Cr20Ni10W2 is one of the representative austenitic heat-resisting alloys. It is usually used for marine diesel engine exhaust valves because of its high strength, excellent heat-resistance and corrosion resistance\(^1\)\(^2\). Determination of the flow behavior for 3Cr20Ni10W2 alloy at hot deformation condition has a great practical importance, since forming processes such as electric upsetting and forging are often applied for metals manufacture\(^3\)\(^4\), and process variables including deformation degree, strain rate and forming temperature have a significant influence on flow behavior which are represented by constitutive equations\(^5\). Moreover, the constitutive relation is often used to describe the plastic flow properties of the metals and alloys in a form that can be used in computer code to perform the numerical simulations of forging response under the prevailing loading conditions\(^6\)\(^7\). In order to establish the optimum processing variables and realize numerical simulation of forging, it is necessary to investigate the constitutive relationships under hot deformation conditions.

In this regard, many constitutive equations have been proposed to describe the flow behavior of materials based on the experimental data. Among these equations, the Arrhenius type equation has been widely used to describe the elevated temperature flow behavior of materials\(^7\)\(^8\). But the traditional Arrhenius type equation is often insufficient in accurately predicting the flow behavior due to lack of the effect of strain on flow stress. By taking the effect of the strain into account, a developed hyperbolic-Sine Arrhenius equation has been proposed to predict the flow stress of various metals or alloys\(^7\)\(^9\)-\(^11\). Lin et al.\(^9\) revised the traditional Arrhenius type equation by introducing strain-dependent parameters (including material constants n, α, β, A and Q) into the constitutive equation. The revised model was proved successful in predicting the flow stress of 42CrMo steel. The high accuracy of such model was also verified in TiAl-Cr-V alloy by Pu et al.\(^7\), Mg-Al4-Z1 alloy by Slooff et al., A356 aluminum alloy by Haghdadi et al.\(^9\). However, few attentions have been paid to model the hot compression behavior of 3Cr20Ni10W2 alloy with such equation.

In the present work, the object is to characterize the general nature of the influence of strain, strain rate and temperature on the compressive flow behavior of 3Cr20Ni10W2 heat-resistant alloy. Toward this end, a series of hot compression tests were carried out at the temperatures of 1203 K, 1253 K, 1303 K, 1353 K and 1403 K, and the strain rates of 0.01 s⁻¹, 0.1 s⁻¹, 1 s⁻¹ and 10 s⁻¹. The effect of processing parameters including deformation temperature and strain rate on flow stress and microstructure was analyzed. The experimental stress-strain data obtained from the compression tests were used to develop the hyperbolic sine constitutive equation describing the relationship of the flow stress, strain rate and temperature by considering
the proper compensation for strain. And then an improved Arrhenius type constitutive equation was constructed to predict the elevated temperature flow behavior for 3Cr20Ni10W2 alloy. Finally, the validity of the theoretical predictions based on the developed constitutive equation has been examined for the entire experimental range.

2. Experimental Procedure

The material used in this investigation is 3Cr20Ni10W2 heat-resistant alloy, and its chemical composition is (wt. %) C 0.25, Si 1, Cr 20, Ni 10, W 2, Fe (balance). The following experimental procedures are according to ASTM Standard: E209-00. Cylindrical specimens with 10mm in diameter and 12mm in height, were machined with flat bottomed grooves on both ends to retain machine oil mingled with graphite powder as lubricant to reduce interface friction between the tools and specimen. A computer-controlled, servo-hydraulic Gleeble 1500 testing machine was used for the isothermal hot compression tests. Three thermocouples were welded at the mid-span of specimen to provide accurate temperature control and measurement during testing. The specimens were resistance heated to the preset temperature at a heating rate of 1 K/s and held for 3 min to equilibrate the temperature throughout the specimens by thermo-coupled-feedback-controlled AC current. Then, the hot compression tests with height reduction of 60% were performed at temperatures from 1203 to 1403 K at an interval of 50 K and strain rates of 0.01 s\(^{-1}\), 0.1 s\(^{-1}\), 1 s\(^{-1}\) and 10 s\(^{-1}\). As soon as the compressions were completed, the specimens were rapidly quenched in water to retain the deformed microstructures at elevated temperatures. In order to observe the microstructure evolution of the alloy under different deformation condition, the specimens were axially sectioned and prepared using standard metallographic techniques. The true stress-strain relationships were derived from the nominal stress-strain curves collected according to the following formula: \(\sigma_T = \sigma_N (1 + \varepsilon_N), \varepsilon_T = \ln(1 + \varepsilon_N)\), where \(\sigma_T\) is the true stress, \(\sigma_N\) the nominal strain, \(\varepsilon_T\) the true strain and \(\varepsilon_N\) the nominal strain\(^1\).

3. Results and Discussion

3.1. True stress and true strain

The true stress-strain curves of 3Cr20Ni10W2 heat-resistant alloy obtained from the hot compression tests at different strain rates and temperatures are illustrated in Figures 1a-d. By comparing these curves with one another, it is observed that the influence of strain, temperature and

![Figure 1. True stress-strain curves of 3Cr20Ni10W2 alloy obtained by Gleeble 1500 under the different deformation temperatures with strain rates: (a) 0.01 s\(^{-1}\); (b) 0.1 s\(^{-1}\); (c) 1 s\(^{-1}\); (d) 10 s\(^{-1}\).](image-url)
strain rate on the flow stress is significant for all the tested conditions.

For a certain curve, the flow stress increases to a peak value in the initial stage of the compression, and then decreases gradually to a steady state. Further, from the experimental results shown in Figure 1a-d, it can be seen that the curve is composed of three stages\(^\text{12}\). In the first stage, the flow stress increases at a declining rate as the softening from dynamic recovery (DRV) becomes higher than the work hardening rate. In the second stage, the flow stress exhibits a smaller and smaller increase until a peak value, which shows that the flow stress is influenced by the combination effect of WH and dynamic softening induced by both dynamic recovery (DRV) and dynamic recrystallization (DRX) so that the softening effect predominates. In the third stage, there are two types of curve variation as follows: decreasing gradually to a steady state as a new balance achieved between dynamic softening and work hardening \((1253-1403 \text{ K} \& 0.01 \text{ s}^{-1}, 1303-1403 \text{ K} \& 0.1 \text{ s}^{-1}, 1353-1403 \text{ K} \& 1 \text{ s}^{-1})\), and maintaining higher stress level without significant softening and work-hardening \((1203 \text{ K} \& 0.01 \text{ s}^{-1}, 1203-1253 \text{ K} \& 0.1 \text{ s}^{-1}, 1203-1303 \text{ K} \& 1 \text{ s}^{-1}, 1203-1403 \text{ K} \& 10 \text{ s}^{-1})\). Thus, it can be concluded that the typical form of flow curve with DRX softening including a single peak followed by a steady state flow as a plateau, is more recognizable at high temperatures and low strain rates. On the contrary, dynamic recovery is dominant at low temperature and high strain rates. It should be noted that the deformation resistance increases with the decrease of deformation temperatures for a given strain rate and decreases with the increase of strain rates for a given deformation temperature; the strain softening phenomenon are more obvious by decreasing strain rates for a given deformation temperature or increasing deformation temperatures for a given strain rate\(^\text{14}\).

### 3.2. Relationship between the process variables and flow behavior

The variation of peak flow stress with tested temperatures and strain rates can be seen more clearly in Figure 2, where the flow stress at peak strain is plotted as a function of the deformation temperature and the logarithm of the strain rate for all deformation conditions in Figure 2a and b, respectively. Figure 3 and Figure 4 show the microstructure at different temperatures and strain rates of 3Cr20Ni10W2 alloy.

#### 3.2.1. Effect of the temperature

The peak flow stress decreases continuously as the deformation temperature rises at a given strain rate as seen from Figure 2a. The reason is that the thermal activation of metal atoms rises with increasing deformation temperature, leading to the more rapid motion of dislocations and vacancies. Thus, the dislocations climb increases, inducing the enhanced dynamic recovery and diminishing flow stresses\(^\text{15}\).

The effects of deformation temperature on the evolution of microstructure can be seen clearly from these optical micrographs in Figure 3. The initial microstructure of 3Cr20Ni10W2 heat-resisting alloy consists of rough equiaxed grains with a large quantity of twin boundaries as shown in Figure 3a. Figure 3b-f shows the microstructure of 3Cr20Ni10W2 heat-resisting alloy in temperature range of 1203 K, to 1403 K and at strain rate of 0.01 s\(^{-1}\), and the equiaxed grains can be easily identified under these deformation conditions, which implied the occurrence of DRX. With the increasing of deformation temperature, dynamic recrystallization becomes noticeable and large-scale. Meanwhile, more and more deformed metal transforms to recrystallized microstructure due to higher mobility of grain boundaries (growth kinetics), and all the grains tend to be more and more homogeneous due to stronger adaptivity for grain boundary migration. Furthermore, when the deformation temperature increased to 1403 K, the size of recrystallized grains increased obviously as shown in Figure 3f. From the above analysis, it is known that the recrystallization becomes easier to take place and accordingly, the dynamic softening effect becomes intense as the deformation temperature increases. Thus, the flow stress decreases with the increasing deformation temperature due to dynamic recrystallization.

![Figure 2](image-url)

**Figure 2.** Effect of the processing parameters on the flow stress at peak strain: (a) effect of the deformation temperature; (b) effect of the strain rate.
3.2.2. Effect of strain rate on flow stress

The effect of deformation strain rates on the flow behavior for 3Cr20Ni10W2 alloy at given temperatures was analyzed by plotting the peak flow stresses as shown in Figure 2b. Peak flow stress and steady state flow stress at a given temperature increase with the increasing strain rate. The dislocation generation, multiplication and intersection rise quickly at higher strain rates, due to the increasing of deformation in unit time. While there is more time for dynamic softening to take place at lower strain rates, leading

![Microstructures at a strain rate of 0.01 s⁻¹ and temperatures of (a) as-received; (b) 1203 K; (c) 1253 K; (d) 1303 K; (e) 1353 K and (f) 1403 K.](image-url)
to the annihilation of dislocation\(^{13}\). Therefore, the dislocation density increases as the strain rate increases, due to which the flow stress increases.

Two types of variant tendencies of the true stress-strain curves with the increasing of strain are exhibit when the true strain exceeds the peak value. The curves drop sharply and then reach nearly steady stress at lower strain rates \((\varepsilon \leq 1 s^{-1})\), while the curves drop rapidly at higher strain rates and do not reach steady state \((\varepsilon > 10 s^{-1})\). The reason is that at lower strain rates, work-hardening due to the multiplication of dislocation and DRX softening due to the annihilation of dislocation can reach a state of balance, and flow stress will keep constant with the increasing strain. Meanwhile deformation comes in a steady state in which complete DRX grains reach equiaxed shape and keep constant size. While at higher strain rates, the curves drop continuously and do not reach the steady flow which is resulted from the unfinished dynamic balance.

The microstructure of 3Cr20Ni10W2 alloy at a deformation temperature of 1403 K, height reduction of 60\% and strain rates ranging from 0.01 \(s^{-1}\) to 10 \(s^{-1}\) is illustrated in Figure 3f and Figure 4. The results show that the size of recrystallised grains decreases with the increasing strain rates. The reason is that the reduction of deformation time restrains the dislocation annihilation, leading to the increasing of nucleation rate, and the growth of recrystallised grains is restrained by the more rapid nucleation. In addition, the microstructure exhibits that more and more deformed metal transformed to recrystallized microstructure with the decreasing of strain rate. At the strain rates of 0.01 \(s^{-1}\) and 0.1 \(s^{-1}\), the microstructures reveal complete recrystallized microstructure and with strain rate decreasing, recrystallized grains are prone to coarsening as shown in Figure 3f and Figure 4a. According to the microstructure analysis, dynamic recrystallization becomes easier to take place with the decreasing of strain rate. Thus, the flow stress decreases as the strain rate decreases.

4. Constitutive Equation of the Flow Stress

In the past, several constitutive equations have been proposed to predict hot deformation behavior of steels and alloys. The most frequently used one is Arrhenius type equation which correlates the flow stress \((\sigma)\) with temperature \((T)\). Further, the influence of the temperatures and strain rate on the flow behavior can be represented by Zener-Hollomon parameter, Z, in an exponent-type equation\(^{16-18}\). The two equations are mathematically expressed as:

\[
Z = \dot{\varepsilon} \exp(Q/RT) \tag{1}
\]

\[
\dot{\varepsilon} = AF(\sigma)\exp(-Q/RT) \tag{2}
\]

Where, \(F(\sigma) = \begin{cases} \sigma^n & \quad \sigma < 0.8 \\ \exp(\beta\sigma) & \quad \sigma > 1.2 \\ \text{[sinh}(\alpha\sigma)]^n & \text{for all } \sigma \end{cases} \)

In the above equations, \(\dot{\varepsilon}\) is the strain rate \((s^{-1})\), \(R\) is the universal gas constant \((8.31\text{J·mol}^{-1}\text{·K}^{-1})\), \(T\) is the absolute temperature (K), \(Q\) is the activation energy \((\text{kJ·mol}^{-1})\), \(\sigma\) is the flow stress \((\text{MPa})\), \(A\), \(\alpha\) and \(n\) are the material constants, \(\alpha = \beta/n\).

4.1. Determination of constitutive equation for peak strain

(1) Calculation of material constants \(n\), \(\alpha\) and \(\beta\) at the peak stress

For the low stress level \((\alpha\sigma < 0.8)\), taking natural logarithms on both sides of Equation 2, the following equation can be obtained:

\[
\ln \dot{\varepsilon} = \ln A + n \ln \sigma - Q/RT \tag{3}
\]

For the high stress level \((\alpha\sigma < 1.2)\), taking natural logarithms on both sides of Equation 2 gives:

\[
\ln \dot{\varepsilon} = \ln A + \beta \sigma - Q/RT \tag{4}
\]

According to Equations 3 and 4, \(n = \frac{d\ln \dot{\varepsilon}}{d\ln \sigma}\) and \(\beta = \frac{d\ln \dot{\varepsilon}}{d\sigma}\). Then, the linear relationships of \(\ln \sigma - \ln \dot{\varepsilon}\) and \(\sigma - \ln \dot{\varepsilon}\) for peak strain at all temperatures were fitted as shown in Figure 5. The lines at different temperatures are almost parallel to each other. The inverse of the slopes of
straight lines in lnσ  - lnε and σ  - lnε plots is accepted as the values of material constants n and β at each tested temperature. Thus the values of n and β at peak strain were obtained by averaging the inverse of slopes under different temperatures, and they were found to be 6.9448 and 0.0315, respectively. Thus, the value of α = β/n = 0.00454.

(2) Calculation of activation energy

Taking natural logarithms on both sides of Equation 2 gives:

\[
\ln \ln \ln \sinh(\alpha\sigma) = A + n \ln (\ln \left(\frac{\sigma}{T}\right) - Q) / RT
\]

For the given strain rate \( \dot{\varepsilon} \), there is a linear relationship between \( \ln \sinh(\alpha\sigma) \) and \( 1/T \), and Equation 5 can be rewritten as

\[
Q = Rn \left[ d \left( \ln \sinh(\alpha\sigma) \right) / d(1/T) \right]
\]

Under different strain rates, the linear relationships between \( \ln \sinh(\alpha\sigma) \) and \( 1/T \) were fitted as in Figure 6a. It is apparent that slopes of the lines at different strain rates are nearly similar with each other. And the average value of all the slopes was accepted as \( Q/Rn \) value. Then substituting into it values of \( \alpha, n \) and \( Q \) provide \( A = 2.5814 \times 10^{25} \text{s}^{-1} \).

(3) Construction of constitutive equation for peak strain

The relationship between \( \dot{\varepsilon}, T \) and \( \sigma \) can be rewritten as:

\[
\dot{\varepsilon} = 2.5814 \times 10^{25} \sinh(0.00454) \exp(-656.860 \times 1) \quad (7)
\]

From Equation 8, it can be seen that the Z parameter increases with the decreasing of deformation temperature and increasing of strain rate, and the flow stress increases as Z parameter increases. The recrystallized microstructure and flow behavior depends on the deformation conditions of temperature and strain rate, and thus on the Z parameter. Decreasing of Z, that is increase of deformation temperature and decrease of strain rate, leads to more extensive DRX. Accordingly, the dynamic softening is more intensive.

4.2. Constitutive equations compensated for strain

As discussed above, the effect of strain on stress are not considered in Equations 1 and 2. However, influence of strain on material constants is significant. Hence, in order to accurately predict the flow behavior of 3Cr20Ni10W2 alloy, it is necessary to establish the constitutive equation compensated of strain into account. This was accomplished...
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by expressing the variable coefficients (including $Q$, $n$, $a$ and $A$) as polynomial functions of strain. In the present work, the values of material constants in Arrhenius type equation were evaluated at different deformation strains within the range of 0-0.9 at intervals of 0.05. These values were then used to fit the polynomial functions (Figure 7), and the variation of $Q$, $\ln A$, $n$ and $\alpha$ with true strain $\varepsilon$ for 3Cr20Ni10W2 alloy could be represented by an eighth order polynomial respectively, as shown in Equation 9. The polynomial fitting results of $Q$, $\ln A$, $n$, and $\alpha$ are given in Table 1.

\[
\begin{align*}
Q &= b_0 + b_1 \varepsilon + b_2 \varepsilon^2 + b_3 \varepsilon^3 + b_4 \varepsilon^4 + b_5 \varepsilon^5 + b_6 \varepsilon^6 + b_7 \varepsilon^7 + b_8 \varepsilon^8 \\
\ln A &= c_0 + c_1 \varepsilon + c_2 \varepsilon^2 + c_3 \varepsilon^3 + c_4 \varepsilon^4 + c_5 \varepsilon^5 + c_6 \varepsilon^6 + c_7 \varepsilon^7 + c_8 \varepsilon^8 \\
\ln \ln 2 &= d_0 + d_1 \varepsilon + d_2 \varepsilon^2 + d_3 \varepsilon^3 + d_4 \varepsilon^4 + d_5 \varepsilon^5 + d_6 \varepsilon^6 + d_7 \varepsilon^7 + d_8 \varepsilon^8 \\
\alpha &= e_0 + e_1 \varepsilon + e_2 \varepsilon^2 + e_3 \varepsilon^3 + e_4 \varepsilon^4 + e_5 \varepsilon^5 + e_6 \varepsilon^6 + e_7 \varepsilon^7 + e_8 \varepsilon^8
\end{align*}
\] (9)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Figure 6. Relationships between: (a) $\ln \sinh(\alpha \sigma_p)$ and $1/T$; (b) $\ln \sinh(\alpha \sigma_p)$ and $\ln \dot{\varepsilon}$.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig7.png}
\caption{Figure 7. Relationships between: (a) $Q$; (b) $\ln A$; (c) $n$; (d) $\alpha$ and true strain $\varepsilon$ by polynomial fit.}
\end{figure}
Substituting $\alpha, n, Q$ and $A$ in Equation 9 into Equation 2 gives the relationships between $\dot{\varepsilon}, T$ and $\sigma$ as following:

$$\dot{\varepsilon} = f(\varepsilon) \left( \sinh(g(\varepsilon)\sigma) \right)^{1/2} \exp\left( -\left( \frac{\varepsilon}{8.31T} \right) \right)$$

(10)

Thus, $Z = \dot{\varepsilon} \exp\left[ \left( \frac{\varepsilon}{8.31T} \right) \right]$. Furthermore, the flow stress, $\sigma$, can be written as a function of $Z$ parameter, substituting the definition of the hyperbolic law can provide:

$$\sigma = \frac{1}{\alpha} \ln \left[ \frac{1}{Z/A^2} + \left( \frac{Z/A^2 + 1}{2} \right)^{1/2} \right]$$

(11)

substituting $\alpha, n, Q, \ln A$ and $Z$ into it Equation 11, the developed Arrhenius constitutive equation for flow behavior of 3Cr20Ni10W2 alloy in a wide strain range of 0-0.9 can be expressed as Equation 12.

$$\sigma = \frac{1}{g(\varepsilon)} \left[ \frac{h(\varepsilon)}{f(\varepsilon)} \right]^{1/2} \left[ \frac{f(\varepsilon)/8.31T}{g(\varepsilon)/8.31T} \right]^{1/2}$$

(12)

Where $f(\varepsilon)$, $g(\varepsilon)$, $h(\varepsilon)$ and $j(\varepsilon)$ are the polynomial functions of $\ln A$, $\alpha, n$ and $Q$ at different true strains, and their expressions are as shown in Equation 9 and Table 1.

4.3. Verification of the developed constitutive equation

Figure 8 shows comparisons between the experimental flow curves and the predicted results calculated from the developed constitutive equations (considering the compensation of strain) at the temperatures of 1203 K, 1253 K, 1303 K, 1353 K and 1403 K, and the strain rates of 0.01 s$^{-1}$, 0.1 s$^{-1}$, 1 s$^{-1}$ and 10 s$^{-1}$. The predicted results are well in agreement with the experimental values. In order to further evaluate the accuracy of the improved constitutive equation, standard statistical parameters such as correlation coefficient ($R$) and average absolute relative error (AARE) are employed$^{24,25}$, which are expressed as following:

$$R = \frac{\sum_{i=1}^{N} (\sigma_{sp} - \sigma_{mp})(\sigma_{sp} - \sigma_{mp})}{\sqrt{\sum_{i=1}^{N} (\sigma_{sp} - \sigma_{mp})^2} \sum_{i=1}^{N} (\sigma_{sp} - \sigma_{mp})^2}$$

(13)

Figure 8. Comparisons between predicted (black circles) and measured (solid lines) of 3Cr20Ni10W2 alloy under different deformation temperatures with strain rates of (a) 0.01 s$^{-1}$; (b) 0.1 s$^{-1}$; (c) 1 s$^{-1}$ and (d) 10 s$^{-1}$.
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In which, \( \sigma_M \) is the experimental data and \( \sigma_P \) is the predicted value obtained from the constitutive equation. \( N \) is the number of data employed in the investigation. The correlation coefficient \( R \) is commonly employed to provide information about the strength of linear relationship between the measured and the calculated values. The average absolute relative error (AARE), which is often used to measure the predictability of a constitutive equation, is also computed through a term-by-term comparison of the relative error.

\[
\text{AARE} = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{\sigma_M - \sigma_P}{\sigma_M} \right| \times 100\%
\]

5. Conclusions

The flow behavior of 3Cr20Ni10W2 alloy have been investigated by means of hot compression tests in the temperature range of 1203-1403 K and the strain rate range of 0.01-10 s\(^{-1}\). The contents are listed as following:

- The flow stress increases rapidly to a peak value in a small strain, and then decreases gradually to a steady state until much higher strain, showing work hardening and dynamic softening coexists during hot deformation. The flow behavior typically exhibited work hardening at the initial stage, then followed by dynamic softening due to DRV/DRX;
- The flow stress decreases with increasing temperature and decreasing strain rate, which can be described by a Zener-Hollomon parameter in an exponential type function. Decreasing of \( Z \), from the increasing of temperature and decreasing strain rate, leads to more extensive of DRV and DRX;
- The effect of strain was incorporated in a novel constitutive equation by expressing the material constants (including \( Q, n, \alpha, \) and \( A \)) as polynomial functions of strain. An eighth order polynomial was suitable to provide a very good correlation;
- The comparisons between the experimental and predicted results show that the two values agreed well with each other throughout the entire experimental range. Further, the values of \( R \) and AARE were determined to be 0.995 and 4.08%, respectively.

Acknowledgements

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### Table 1. Polynomial fitting results of \( Q, n, \ln A, \) and \( \alpha \) of 3Cr20Ni10W2 alloy.

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<th>( Q (KJ) )</th>
<th>( n )</th>
<th>( \ln A )</th>
<th>( \alpha )</th>
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Figure 9. The correlation between the experimental and predicted flow stress data from the developed constitutive equation over the experimental range of strain, strain rate and temperature.
References


