PREDICTION OF STRESS-STRAIN CURVE BEHAVIOR OF A MODIFIED NIMONIC 263 SUPERALLOY

KODZHASPIROV Georgii[1], TERENTYEV Maxim[1]

[1]*Peter the Great St.Petersburg Polytechnic University, St.Petersburg, Russian Federation*
gkodzhaspirovr@gmail.com, maxteen@list.ru

Abstract

The hot deformation behavior of a modified nickel-based Nimonic 263 superalloy, based on the physical simulation using torsion tests at different deformation temperatures (1200°C, 1050°C and 900°C) and strain rates (0.01, 0.1 and 1 s^{-1}) has been studied. The flow stress curves showed an initial strain-hardening followed by a peak stress revealing the occurrence of dynamic recrystallization. Based on the data result in the hot torsion tests, equations, allowing to predict the stress-strain curves behavior under different temperature-strain rate conditions, had been derived. The obtained equations can be used for FEM-simulation of real hot deformation processes of Nimonic 263-type alloys.

Keywords: Superalloy, stress-strain curve, simulation, Nimonic 263, dynamic recrystallization

1. INTRODUCTION

It is well known that the techniques allowing to reduce the time and cost for designing a new metal processing technologies give manufacturers greater competitiveness within the marketplace. One of such methods is simulation of hot metal-forming processes (e.g. extrusion, rolling or forging) with the aids of finite element software. Such a computer aided engineering technique enables to carry out virtual experiments in a very short time and with significantly less cost than real physical trials.

One of the most important data for FE-simulation is the information on the stress-strain curve behavior under different hot deformation conditions. Stress-strain curves of a specific alloy may be described as a number of functions of strain, strain rate, and temperature.

The aim of the present research was to obtain equations that would allow to predict stress-strain curves of Nimonic 263 alloy with a modified chemical composition for any combination of hot deformation parameters.

2. EXPERIMENTAL PROCEDURES

Chemical composition of the modified Nimonic 263 alloy is shown in **Table 1**.

Table 1 Chemical composition of the alloy, %wt

Ni	Cr	Fe	C	S	Co	Mo	Ti	Al	Nb
51.4	19.0	~ 0.8	0.05	0.05	19.3	5.7	2.6	~ 1	0.12

To study the hot deformation behavior under different temperature-strain parameters the torsion tests were carried out. The experiments were carried out at the different deformation temperatures (1200 °C, 1050 °C and 900 °C) and strain rates (0.01, 0.1 and 1 s^{-1}).

Specimens for torsion tests were cut from a forged piece. Before deformation all the samples were heated to 1200°C, soaked at this temperature to obtain equal temperature over the cross section and dissolve possible precipitates, then cooled to the desired deformation temperature.

During the torsion tests the change in torsion angle and load were recorded. Data on torsion angle and load was converted to the true stress and true strain values according to the procedure described in [1]. All the stress-strain curves, obtained after analysis of torsion tests data then were corrected for deformation heating as described in [1].

Initial austenite grain size of the alloy before deformation was measured on the polish sections prepared from the specimens heated up to 1200°C, soaked at this temperature and rapidly cooled without any deformation.

3. RESULTS AND DISCUSSION

Actual and corrected stress-strain curves are shown in the **Figure 1**.

As can be seen from the figure deformation heating does have an effect on the flow stress and the most pronounced effect takes place in case of relatively high strain rates and relatively low deformation temperatures (900°C) as it was noted in [2]. Most of the corrected flow stress curves showed an initial strain-hardening followed by a peak stress revealing the possible occurrence of dynamic recrystallization. The occurrence of peak stress in case of deformation at 900 °C most likely is connected with premature failure of the specimens: no recrystallized grains were found in these specimens. It can be noticed that peak stress values increase with the increasing of strain rate and decreasing of deformation temperature, as expected.

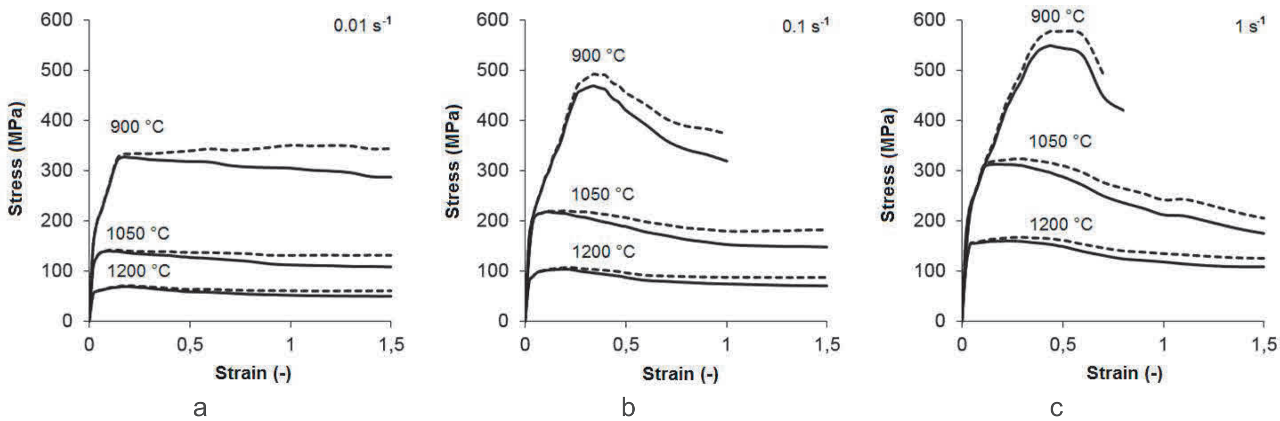

Figure 1 Corrected (dash line) and measured (solid line) stress-strain curves of the alloy

Zenner-Hollomon parameter *(Z)* and its approximation by hyperbolic sine proposed by Sellars and Tegart [3] was used to estimate the hot deformation activation energy and to describe the flow stress of the alloy.

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right) = A\left[\sinh\left(\alpha\sigma_p\right)\right]^n \tag{1}$$

Expression for peak stress (σ_p) can be derived after estimation of all the parameters of the Equation 1:

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

Steady state stress (σ_{ss}) can be predicted using the same type of equation as well. Thus, after implementation of the same procedure an equation for prediction of σ_{ss} was obtained.
For prediction of strain at peak stress (ε_p) the following equation was used [4]:

$$\varepsilon_p = AD_0^m Z^n \tag{3}$$

where D_0 - initial grain size, m and n are material constants.

Provided that the specimens for this investigation were cut from the same forged piece and had the same initial austenite grain size (337 microns), AD_0^m can be considered as a constant B. Thus, Equation 3 can be written as:

$$\varepsilon_p = BZ^n \tag{4}$$

For prediction of stress before σ_p the modified Voce`s equation was used [5]:

$$\sigma = \sigma_p\left[1-\exp(-C\varepsilon)\right]^m \tag{5}$$

where m is a material constant and C is a function of Z of the same type as Equation 4:

$$C = AZ^b \tag{6}$$

For prediction of the curve after σ_p the following equation was used [5]:

$$\sigma = \sigma_p - (\sigma_p - \sigma_{ss})X \tag{7}$$

where X - is the apparent recrystallized volume fraction.

Equation 7 is based on the consideration that metal softening due to dynamic recrystallization (DR) is proportional to the fraction recrystallized, X. Here it is also considered that DR starts at ε_p, which is not true from the point of view of real microstructure evolution [6, 7].

$$X = 1 - \exp\left[-0{,}693\left(\frac{\varepsilon - \varepsilon_p}{\dot{\varepsilon}\cdot t_{50}}\right)^n\right] \tag{8}$$

where t_{50} is time for recrystallization of 50% volume, which is calculated using the following formula:

$$t_{50} = AD_0^n \dot{\varepsilon}^m \exp\left(\frac{Q_{rec}}{RT}\right) \tag{9}$$

where D_0 - initial grain size., $Qrec$ - recrystallization activation energy, A,m,n - material constants.

Provided that the specimens for this investigation were cut from the same forging and had the same initial austenite grain size, AD_0^n can be considered as a constant B and the equation can be rewritten as

$$t_{50} = B\dot{\varepsilon}^m \exp\left(\frac{Q_{rec}}{RT}\right) \tag{10}$$

All the coefficients of Equations 1 - 10 obtained after analysis of the corrected stress-strain curves are summarized in **Table 2**. Predicted and actual stress-strain curves are plotted in **Figure 2**. As can be seen from the figure there is acceptable agreement between the calculated and experimental curves.

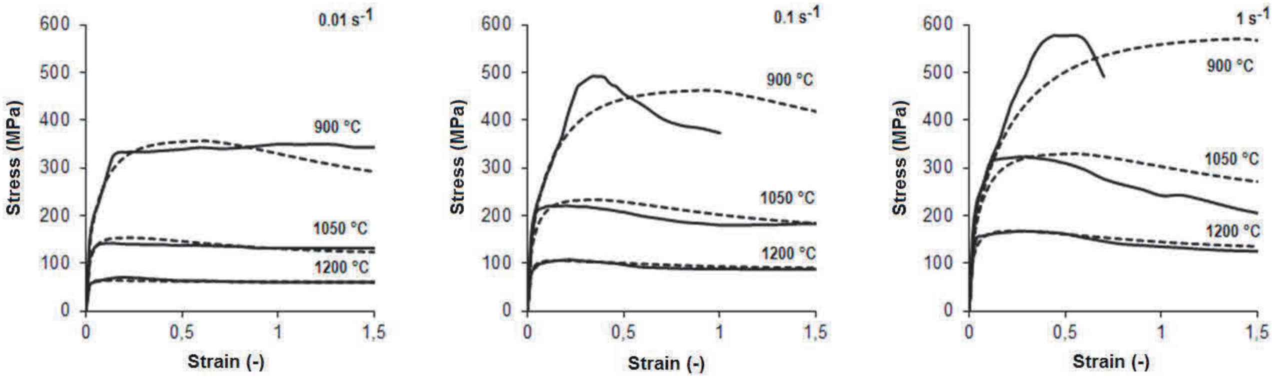

Figure 2 Predicted (dash line) and actual (solid line) stress-strain curves of the alloy

Table 2 Coefficients of the equations for prediction the flow stress behavior

Equation	Coefficients
$Z=\dot{\varepsilon}\ \exp\left(\frac{Q}{RT}\right)$ $\sigma_p=\frac{1}{\alpha}\ln\left[\left(\frac{Z}{A}\right)^{1/n}+\sqrt{\left(\frac{Z}{A}\right)^{2/n}+1}\right]$	Q=447960 J/mol α= $4.652\cdot10^{-3}$ MPa^{-1}; A = $1.494\cdot10^{16}$ s^{-1}; n = 4.394
$\sigma_{ss}=\frac{1}{\alpha'}\ln\left[\left(\frac{Z}{A'}\right)^{1/n'}+\sqrt{\left(\frac{Z}{A'}\right)^{2/n'}+1}\right]$	α'= $4.652\cdot10^{-3}$ MPa^{-1}; A'= $9.812\cdot10^{16}$ s^{-1}; n'= 5.690
$\varepsilon_p=BZ^n$	B = 3.842 10^{-4}; n = 0.178
$\sigma=\sigma_p[1-\exp(-C\varepsilon)]^m$ $C=AZ^b$	m = 0,5 A = 138670; b = -0.235
$t_{50}=B\dot{\varepsilon}^m\exp\left(\frac{Q_{rec}}{RT}\right)$	B = 01090; m = -0.923; Q_{rec} = 23131 J/mol

4. CONCLUSION

A mathematical model consisting of a number of equations for prediction of Nimonic 263 alloy flow stress-strain curves under different deformation conditions was obtained. The obtained model can be used for FEM-simulation of real hot deformation processes of Nimonic 263 type alloys.

REFERENCES

[1] DIETER, G. E., et al. *Handbook of Workability and Process Design*. ASM International, 2003. 414 p.

[2] LAASRAOUI, A., JONAS, J. J. Prediction of Steel Flow Stresses at High Temperatures and Strain Rates. *Metallurgical Transactions A*, 1991, vol. 22A, pp. 1545-1558.

[3] SELLARS, C. M., TEGART, W. J. M. Relationship between strength and structure in deformation at elevated temperatures. *Mem. Sci. Rev. Metallurgie*, 1966, vol. 63, pp. 731-745.

[4] FURRER, D. U., SEMIATIN, S. L. *ASM HandBook, Volume 22B - Metals Process Simulation.* ASM International, 2010, 708 p.

[5] SZTWIERTNIA K. *Recrystallization.* InTech, 2012. 464 p.

[6] KODZHASPIROV, G. E., TERENT'EV, M. I., FILIPPOV S. A. Effect of Hot Deformation Parameters on Austenitic Ni - Co - Cr - Mo-Alloy Microstructure Evolution. *Metal Science and Heat Treatment*, 2014, vol. 56, pp. 239-244.

[7] POLIAK, E.I. JONAS, J.J. Initiation of Dynamic Recrystallization in Constant Strain rate Hot Deformation. *ISIJ International*, 2003, vol. 43, no. 5, pp. 684-691.