

PAPER • OPEN ACCESS

Constitutive model of Ti-25Nb alloy

To cite this article: Jianjun Liu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **493** 012154

View the [article online](#) for updates and enhancements.

Constitutive model of Ti-25Nb alloy

Jianjun Liu, Kelu Wang*, Xin Li and Jing Cheng

School of Aerospace Manufacturing Engineering, Nanchang Hang Kong University,
Nanchang 330063, China

*Corresponding author e-mail: wangkelu@126.com

Abstract. The flow stress curves of Ti-25Nb alloy were acquired by hot compressive tests on Gleeble-3500 thermo-simulation machine at the strain rate range of $0.001-10 \text{ s}^{-1}$ and temperature range of $470-620^\circ\text{C}$. The results show that the flow stresses decrease with the decrease in strain rate and the increase in temperature in general and modified constitutive model established by Strain compensation of n and A has a high predicted ability under experimental deformation condition.

1. Introduction

Biomedical titanium alloys play a critical role in biomedical materials [1]. In the past decades, biomedical titanium alloys have been successfully developed in this world. Nowadays, as the new generation biomedical titanium alloys, Ti-25Nb alloys are more outstanding than other material in so many aspects. As a result, it is meaningful and significant to research this alloys for every citizen. Establishing the constitutive models is really critical for processing in factory and simulation in future research.

Some researchers studied the compositions with different Ti/Nb atomic ratios obtained by reactive milling (RM) and mechanical alloying (MA) [2]. They got conclusions that the RM synthesized hydrides acquired better H-absorption/desorption properties at $250-300^\circ\text{C}$ and the hydride nucleation manner changes with increasing the Nb addition. Unfortunately, there are hardly constitutive models of Ti-25Nb alloys in the past studies. In this paper, the true stress-strain curves obtained from experiments were analyzed and the constitutive model was established by combining the Zener-Hollomon parameter and the Arrhenius-type equation.

2. Materials and methods

The chemical compositions of Ti-25Nb alloys used in this research are 85.3 at% Ti and 14.7 at% Nb. The specimens for isothermal compression tests were machined into cylinders 12 mm in height and 8 mm in diameter. The hot compression testing was carried out in the temperatures range of $470-620^\circ\text{C}$ and strain rates range of $0.001-10 \text{ s}^{-1}$ by Gleeble-3500 thermal-mechanical simulator. The samples were extremely compressed 70% in height and the true strain was 1.2 relatively.

3. Results and discussion

3.1. Flow behaviour

The true stress-strain curves obtained at different temperatures and strain rates (Fig. 1) show that the true stress increases rapidly at the initial stage in each curve, which results from work hardening caused



by the rapid augmentation of the dislocation density. Then, stresses quickly reach peak with greatly small strains. After peak stresses, stresses decrease gradually with the increase in strain at the same train rate and temperature.

As Fig. 1(a), the stresses reduce with the decrease in strain rate at the same temperature in general. As Fig. 1(b), the stresses decrease with the increase in temperature in general at the same strain rate. As a result, the temperature and strain rate make a significant difference in the true stress. In this experiment, there are work hardening and dynamic softening caused by DRV and DRX. Generally, the true stress-strain curves mainly show DRX characteristics with obvious peak stresses, which is a matter of balance between working hardening and dynamic softening.

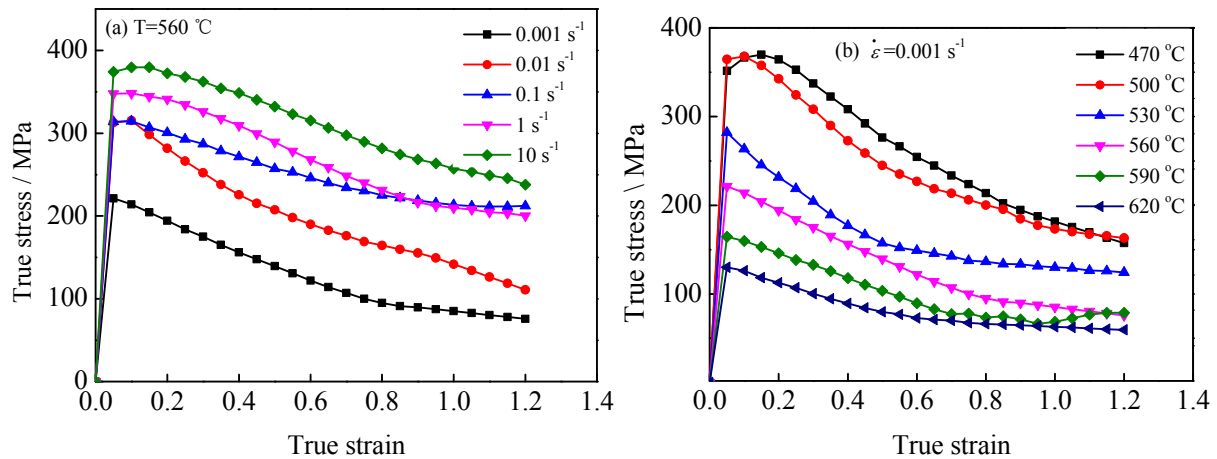


Figure 1. True stress-true strain curves of Ti-25Nb alloys at different deformation conditions (a) $T=560^{\circ}\text{C}$, (b) $\dot{\varepsilon}=0.001\text{ s}^{-1}$.

3.2. Constitutive model

The Arrhenius-type equation could be generally used to describe the hot deformation behavior of a material. In addition, the Zener-Hollomon parameter proposed by Zener and Hollomon is a valid way to state the effect of deformation temperature and strain rate on flow stress. Generally, the flow stresses of a material can be modeled by combining the Zener-Hollomon parameter and the Arrhenius-type equation, as shown in Eqs. (1) [4-6].

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right) = \begin{cases} A_1 \sigma^{n_1} & (\alpha\sigma < 0.8) \\ A_2 \exp(\beta\sigma) & (\alpha\sigma > 1.2) \\ A[\sinh(\alpha\sigma)]^n & (\text{for all}) \end{cases} \quad (1)$$

Where $\dot{\varepsilon}$ is the strain rate (s^{-1}), Q is the activation energy of hot deformation (kJ/mol), R is the gas constant (8.314 J/mol/K), T is the absolute temperature(K), σ is flow stress (MPa), A_1 , A_2 , A , n_1 , n , α , and β are the material constants.

By considering the value of peak stress (σ_p), the average values of n_1 , β and n acquired by Eq. (2)-(4) was found to be 18.089, 0.0562 and 13.472 as shown in Fig. 2a-c.

$$n_1 = \left[\partial \ln \dot{\varepsilon} / \partial \ln \sigma_p \right]_T \quad (2)$$

$$\beta = \left[\partial \ln \dot{\varepsilon} / \partial \sigma_p \right]_T \quad (3)$$

$$n = \left[\frac{\partial \ln \dot{\epsilon}}{\partial \ln (\sinh (\alpha \sigma_p))} \right]_T \quad (4)$$

As a result, the value of α obtained from $\alpha = \beta / n_1$ was found to be 0.00311. The activation energy of hot deformation (Q) can be calculated from Eq. (5):

$$Q = Rn \left[\frac{\partial \ln (\sinh (\alpha \sigma_p))}{\partial (1/T)} \right]_{\dot{\epsilon}} \quad (5)$$

The average slopes of $\ln [\sinh (\alpha \sigma_p)]$ against $1000/T$ was found to be 5.726 as shown in Fig. 2d. So the value of Q could be calculated to be 641.3 kJ/mol. Moreover, the value of $\ln A$ was acquired by the average intercepts of line $\ln [\sinh (\alpha \sigma_p)] - \ln Z$ as shown in Fig. 3. All in all, the peak stress of Ti-25Nb alloy could be expressed by Eq. (6).

$$Z = \dot{\epsilon} \exp \left(\frac{6.413 \times 10^5}{RT} \right) = 6.858 \times 10^{38} [\sinh (0.00311 \sigma)]^{13.472} \quad (6)$$

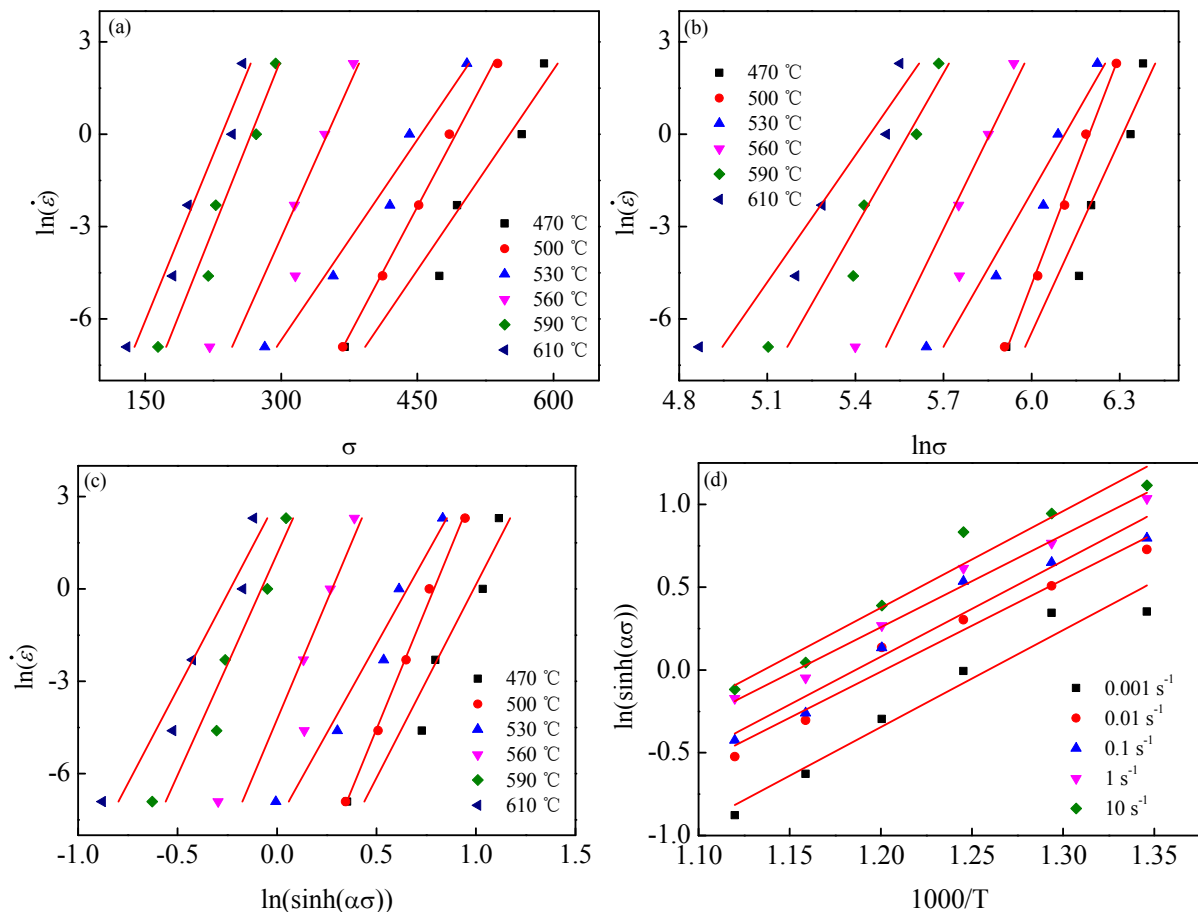


Figure 2. The relationship between (a) $\sigma - \ln \dot{\epsilon}$, (b) $\ln \sigma - \ln \dot{\epsilon}$, (c) $\ln (\sinh (\alpha \sigma)) - \ln \dot{\epsilon}$, (d) $1000/T - \ln (\sinh (\alpha \sigma))$.

In this modified model, based on the peak stress proposed by Mirada [7], the activation energy (Q) and α are not assumed to be a function of strain. Moreover, the material constants A and n , calculated at different strains by previous mentioned approach, are strain dependents in this modified approach. The

main advantageous of this new model is that the cost of computation and time is reduced mostly as Q and α are constants and just only are calculated at the peak stress.

In the present study, $\ln A$ and n were calculated between 0.05 and 1.2 with intervals of 0.05 to establish this modified model. The order polynomial curve of $\ln A$ and n was shown in Fig. 4.

Considering strain-independent Q and α and strain-dependent A and n , the modified model equation can present in the following form:

$$\sigma = \frac{1}{\alpha} \left[\sinh^{-1} \left(\frac{Z}{A(\varepsilon)} \right)^{1/n(\varepsilon)} \right] \quad (7)$$

Comparisons between the experimental stresses and predicted data calculated by Eqs. (7) at different conditions are plotted in Fig. 5. It can be seen from Fig. 5 that the modified constitutive model can accurately predict the flow stress of Ti-25Nb alloy.

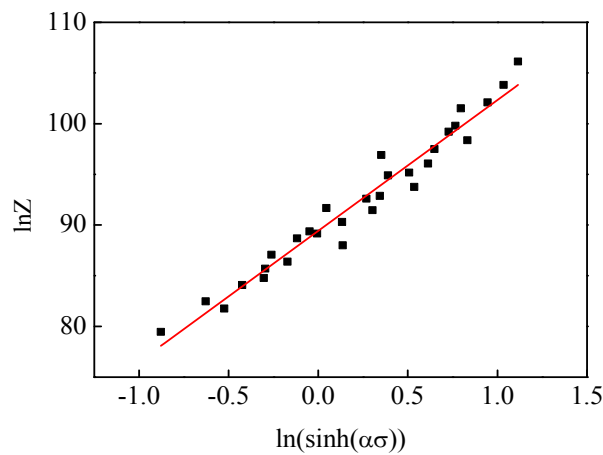


Figure 3. The relationship between $\ln(\sinh(\alpha\sigma))$ - $\ln Z$.

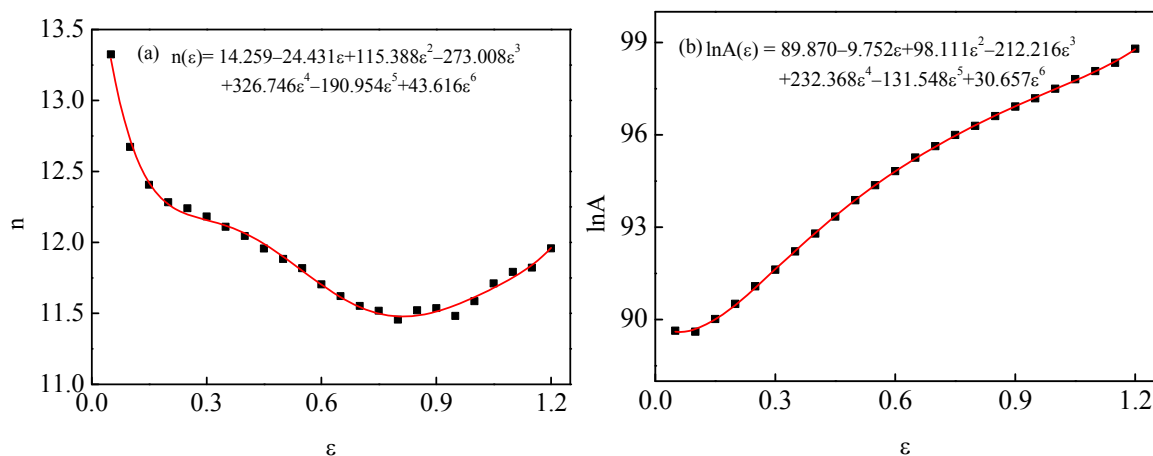


Figure 4. The 6th order polynomial of (a) n and (b) $\ln A$ with true strain

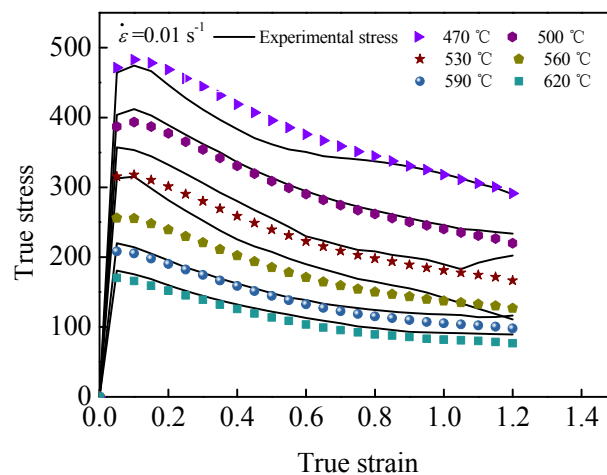


Figure 5. Comparison between the experimental and predicted flow stresses on the strain rates of 0.01 s^{-1} .

4. Conclusion

The hot deformation behavior of Ti-25Nb alloys was investigated at deformation temperatures 470, 500, 530, 560, 590 and 620 °C and at strain rates 0.001, 0.01, 0.1, 1, and 10 s^{-1} . The conclusions are presented below.

(1) The flow stresses of Ti-25Nb alloys decrease with the decrease in strain rate and the increase in temperature in general.

(2) To predict the flow stresses of Ti-25Nb alloys, modified constitutive model was established by strain compensation of n and A and has a high predicted ability under experimental deformation condition.

Acknowledgments

This work was financially supported by National Natural Science Foundation of China (Grant No. 51464035).

References

- [1] Y.Y. Gu, F.J. Fan, Y.H. Guo, et al. Diffusion and atomic mobility of BCC Ti-Al-Nb alloys: Experimental determination and computational modeling, *Calphad*. 62 (2018) 83 - 91.
- [2] R.de Araujo-Silva, A.M. Neves, L.E.R. Vega, et al. Synthesis of β -Ti-Nb alloys from elemental powders by high-energy ball milling and their hydrogenation features, *International Journal of Hydrogen Energy*. 43 (2018) 18382 - 18391.
- [3] Y. Liu, C. Geng, Q.Q. Lin, et al. Study on hot deformation behavior and intrinsic workability of 6063aluminum alloys using 3D processing map, *Alloys Compd.* 713 (2017) 212 - 22.
- [4] C.M. Sellars, W. McTegart, On the mechanism of hot deformation, *Acta Metall.* 14(1966) 1136 - 1138.
- [5] S. Medina, C. Hernandez, General expression of the Zener-Hollomon parameter as a function of the chemical composition of low alloy and microalloyed steels, *Acta Mater.* 44 (1996) 137-148.
- [6] Z. Shi, X. Yan, C. Duan, Characterization of hot deformation behavior of GH925 superalloy using constitutive equation, processing map and microstructure observation, *Alloys Compd.* 652 (2015) 30 - 38.
- [7] H. Mirzadeh, *Metall. Mater. Trans. A*. 46A (2015) 4027 - 4037.