Mechanical characterization and analytical modeling of the thermo-viscoplastic behaviour AISI 304 steel under wide ranges of strain rates at room temperature

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1. General

In this contribution, the thermo-viscoplastic behaviour of the steel AISI 304 is analyzed under wide ranges of loading conditions. In order to characterize the mechanical behavior of the material, tensile tests have been performed within the ranges of strain rates $10^{-4} \leq \dot{\varepsilon} \leq 10^{3}\ s^{-1}$. The analytical definition of the material behaviour has been conducted by means of the extended Rusinek-Klepaczko model to viscous drag effects [1]. Based on such understanding of the material behaviour, satisfactory agreement between experiments and analytical modeling is reached for the whole range of loading conditions examined.

2. Experimental characterization at room temperature

Analysis of the thermo-viscoplastic behaviour of the steel AISI 304 has particular relevance since this material is widely used in many engineering applications. The tensile tests performed at different strain rates reveal the characteristics high strain hardening and ductility of this metal, Figure 1-a. It has to be highlighted that even at high loading rate the strain hardening of the material remains approximately constant. It provides to this material of improved mechanical properties for absorbing energy under impulsive loads. Dependence of strain rate on the material flow stress level is observed. Thus, in Figure 1-b. is illustrated the rate sensitivity of the material from static to highly dynamic loading. The original experimental results of this work are compared with those reported in [2]. Both data find good agreement within the range of strain rates considered. In particular, it has to be noted that beyond certain level of loading rate the flow stress of the material sharply increases. Such a behaviour is assumed to be caused by viscous drag deformation mode [2].

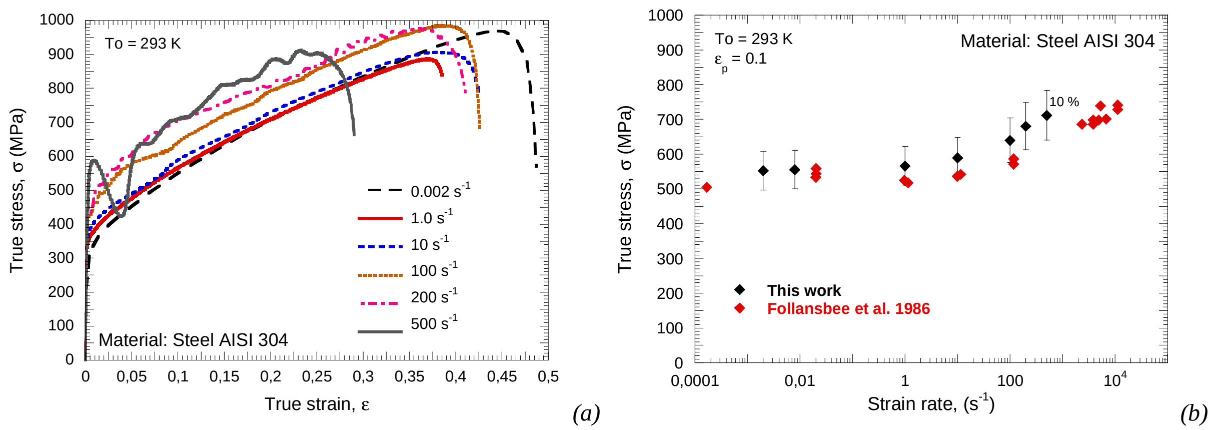

Figure 1. (a) Flow stress evolution as a function of plastic strain for different strain rates at room temperature (b) Flow stress evolution as a function of strain rates and comparison with [3]

3. Thermo-viscoplastic modeling of 304 stainless steel for a wide range of strain rates

For modeling the material behaviour, the extended Rusinek-Klepaczko model to viscous drag effects [1] is applied:

$$\bar{\sigma}\left(\bar{\varepsilon}^{p},\dot{\bar{\varepsilon}}^{p},T\right)=\frac{E(T)}{E_0}\left[\sigma_{\mu}\left(\bar{\varepsilon}^{p},\dot{\bar{\varepsilon}}^{p},T\right)+\sigma^{*}\left(\dot{\bar{\varepsilon}}^{p},T\right)\right]+\sigma_{vs}\left(\dot{\bar{\varepsilon}}^{p}\right) \qquad (1)$$

An additional stress component $\sigma_{vs}\left(\dot{\bar{\varepsilon}}^{p}\right)$ originally proposed by [3] is added to the original Rusinek-Klepaczko formulation in order to describe the viscous drag effects at high strain rates. The following set of constants for the model calibration has been found, Table 1.

B_0 (MPa)	ν (-)	n_0 (-)	D_2 (-)	ε_0 (-)	σ_0^* (MPa)	m^* (-)	D_1 (-)	χ (MPa)	α (-)	θ^*
1243.6	0.001	0.36	0.035	0.0118	117.72	1.29	0.55	200.83	0.0009774	0.9

Table 1. Material constants for the steel AISI 304, equation 1

By means of such analytical description of the material behaviour, good agreement between experiments and modeling is found at room temperature for the whole range of loading conditions considered, Figure 2.

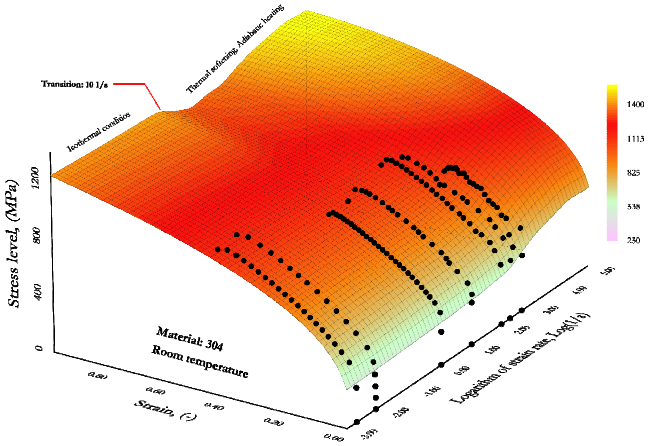

Figure 2. Comparison between experiments and analytical predictions for wide ranges of strain rates

4. Conclusions

In this investigation, the thermo-viscoplastic behaviour of the steel AISI 304 has been examined. The experimental characterization of the material has been conducted in tension under wide ranges of strain rates. An analytical description of the macroscopic behaviour of this metal is reported. For such goal, the extended Rusinek-Klepaczko model to viscous drag effects is applied. It allows for proper description of the material behaviour within the whole range of loading conditions considered. In addition, the analytical formulation proposed gathers limited number of material constants and simple calibration procedure.

References

[1] A. Rusinek and J. A. Rodríguez-Martínez (2009). Thermo-viscoplastic constitutive relation for aluminium alloys, modeling of negative strain rate sensitivity and viscous drag effects, *Mater. Des.*, **30**, 4377–4390.

[2] P.S Follansbee (1986). *High-Strain-Rate Deformation of FCC Metals and Alloys***,** Metallurgical Applications of Shock-Wave and High-Strain-Rate Phenomena, 451-479.

[3] R. Kapoor and S. Nemat-Nasser (1999). Comparison between high strain-rate and low strain-rate deformation of tantalum, *Metall. Mater. Trans.*, **31A**, 815–823.