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MECHANICAL BEHAVIOR OF A WARM-ROLLED VANADIUM MICROALLOYED MEDIUM CARBON STEEL

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Abstract. *The application of small microalloying additions in carbon steel is well known. Addition elements such as niobium and vanadium can have a number of effects on the microstructure which affect the mechanical properties of microalloyed steels. These effects include nitrogen fixing, grain refinement, interlamellar spacing and precipitation strengthening. In medium carbon steels the limited solubility of niobium in austenite at normal soaking temperatures restricts the potential of this element. However, as vanadium shows a high level of solubility, significant levels of dispersion strengthening in vanadium microalloyed steels have allowed the development of medium carbon forging steels for several applications such as connecting rods and steerings linkages. The strength level attained in microalloyed medium carbon steels and cost savings by developing the properties without heat treatment have resulted in an extensive application of those steels in industrial scale. This work has studied the mechanical behavior under warm work of a vanadium microalloyed medium carbon steel in the intercritical temperature range focused in the decomposition of the ferrite-austenite. Isothermal continuous and interrupted torsion tests were carried out for temperatures ranging from 1100^{o}C to 600^{o}C and with deformation rate of 0.5 and 1.0s^{-1} .*

Keywords: *Microalloyed steel, Warm work, Torsion tests*

1. INTRODUCTION

Microalloyed steels are largely used for industrial applications. Small addition of elements such as Nb, V and Ti, in a combined or individual basis, during the manufacturing of those steels conducts to the formation of carbonitrates, which act by decreasing austenite grain size. Depending on their chemical composition, microalloyed steels can be submitted to a range of metallurgical processes from forging to rolling.

Conventional rolling is applied with the only aim to provide a final shape to products. However, controlled rolling can additionally establish mechanical and microstructural properties for the final products by means of control of hot work parameters.

Controlled rolling was firstly developed by using temperatures higher than that for the austenite-ferrite transformation. This process is called two-stage rolling. First stage rolling occurs in the austenite recrystallization region, in which deformation and recrystallization occur simultaneously. Second stage of controlled rolling occurs in a region of lower temperature, in which there is no more total austenite recrystallization. If the end of deformation occurs before the start of austenite-ferrite transformation, the energy accumulated during the deformation is released during the transformation and, a small effect from deformation is retained in the ferritic grains (Tanaka, 1995). It is well know the importance of the final rolling temperature over the mechanical properties of commercial steels for final rolling temperatures placed above the austenite-ferrite transformation temperature, i.e. in the austenitic region. It was the attempts to achieve grain refinement of microalloyed steel, which led to the development of controlled rolling in the austenite-ferrite transformation region promoting an increase in mechanical properties of steel (Stuart and Wilson, 1981).

2. MATERIALS AND EXPERIMENTAL PROCEDURES

A medium carbon steel was studied in this work. The chemical composition of this steel is given in Table 1.

Table 1. Chemical composition of the steel tested in %weight

Chemical composition	C	Si	Mn	V	N	Nb	Al
% (weight)	0.39	0.62	1.3	0.11	0.013	0.003	0.025

Mechanical tests were performed on the computerized torsion machine developed by DEMa-UFSCar (Jorge Jr., 1991). The sample had central gage section of 21mm in length and 6.2mm in diameter and were heated by means of an infra-red furnace assembled on the test machine. Chromel–Alumel thermocouples were used to monitoring temperature during the tests.

Torsion tests were conducted over a temperature range from 600^0C to 1150^0C and at equivalent strain rates of $0.5s^{-1}$ and $1.0s^{-1}$. Samples were heated from room temperature to a soaking temperature of 1150^0C during 10 minutes, followed by cooling to test temperature in which the samples were held for 1 minute. This schedule is shown in Figure 1.

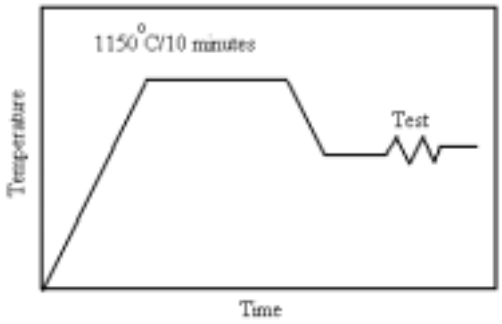

Figure 1 - Temperature- time schedule applied in isothermal tests carried out on cooling.

The critical temperatures Ar3 and Ar1 were determined through dilatometer tests, and they are shown in Table 2.

Table 2. Critical temperatures Ar_3 and Ar_1.

Cooling rate (^{0}C/s)	Ar_3 (^{0}C)	Ar_1 (^{0}C)
0.2	728	638
0.5	722	610
1.0	710	600

3. RESULTS AND DISCUSSION

The isothermal flow curves were determined at a strain rate of $0.5s^{-1}$ and $1.0s^{-1}$, and temperature ranging from 1150 ^{0}C to 600 ^{0}C. They are shown in Figures 2 and 3.

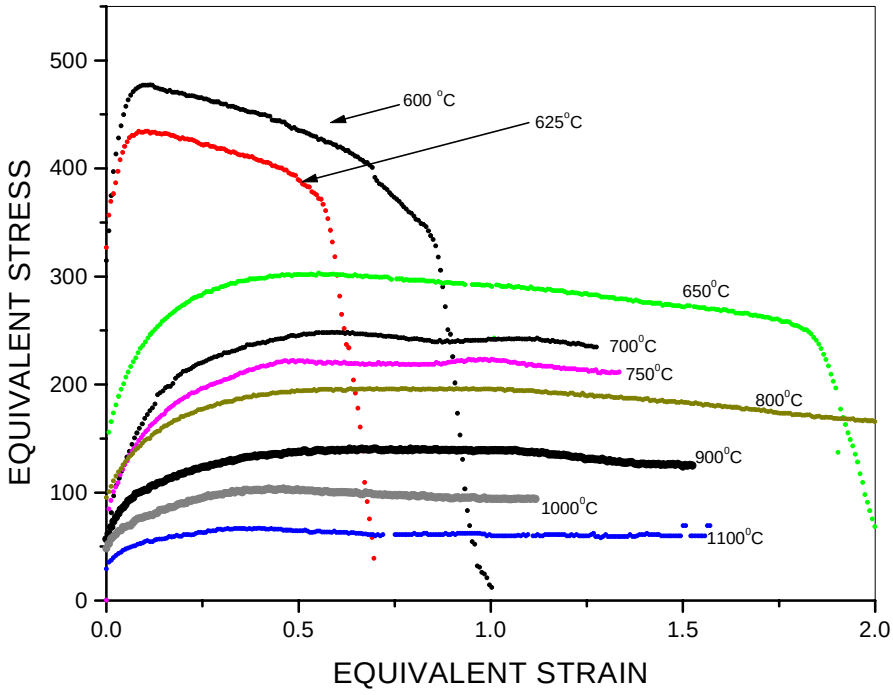

Figure 2 - Flow curves on cooling with deformation rate of $0.5s^{-1}$

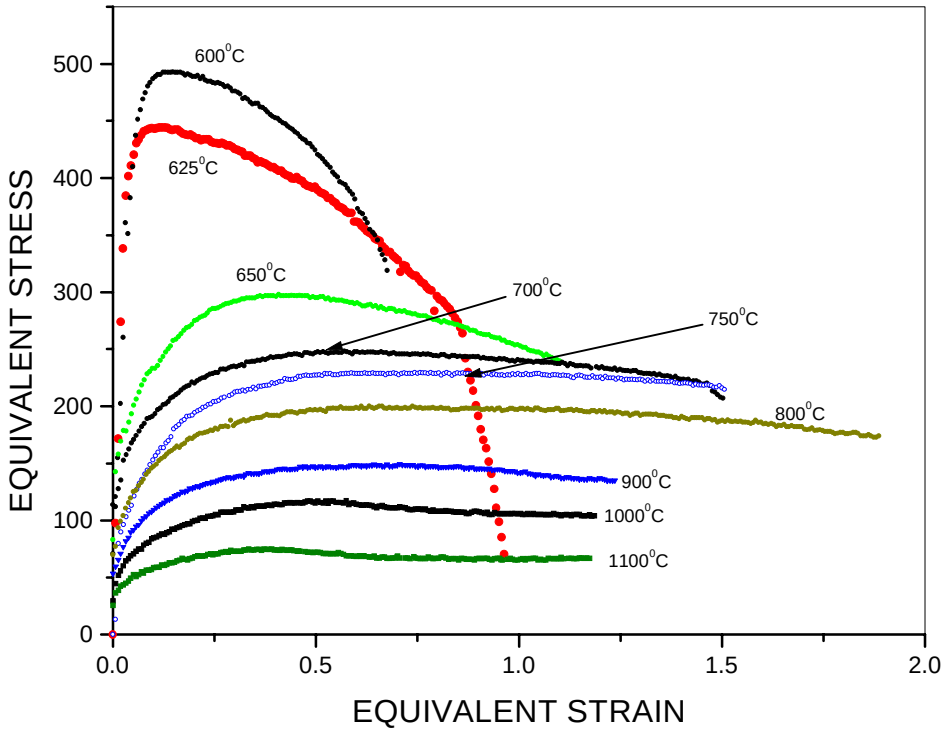

Figure 3 - Flow curves on cooling with deformation rate of $1.0s^{-1}$

From Figures 2 and 3 it is possible to observe distinct flow curves as a function of temperature. At temperatures over 650^0C the flow curve seems like softened by dinamic recovery. At decreasing temperatures, below 650^0C, the flow shape changes abruptly with strong work hardening to a hump and a later extensive softening. The apparent activation energy was determined using the relationship proposed by Sellars and Tegart (1966) in Eq. (1):

$$\varepsilon exp(Q/RT) = A\{sinh(\alpha\sigma)\}^n = Z \qquad (1)$$

where ε is the strain rate, σ is the peak stress, Q is the activation energy of deformation, T is the temperature, A, α, n and R are constants, and Z is the Zener–Holloman parameter. The activation energy determined in this temperature range for sample deformed at $1s^{-1}$ was 593 kJ/ mol. The activation energy to high temperature was previously determined in a recent work as 340 kJ/mol. (Lourenço and Balancín, 1996). The higher activation energy obtained can be correlated with the deformation in the austenite–ferrite region (Briottet et al, 1996). The plots of ln Z *vs* ln (sinh(α.σ)) corresponding to deformation in austenite range and austenite-ferrite range is presented in figure 4.

The flow curve behavior at temperatures below 650^0C, as shown in Figs. 2 and 3 has been reported for steels that obeys Kurdjomov-Sachs relationship. The ferrite nucleates at austenite grain boundary due to the energetically favorable sites for nucleation and the higher diffusion rates present in the boundary. The nucleus will have an orientation relationship with

one of its two neighboring austenite grains. This orientation is known as Kurdjomov-Sachs relationship. In this orientation the planes (110) from ferrite and (111) from austenite are parallel, and so are the directions [100] from ferrite and [110] from austenite (Honeycombe, 1976). When the transformation occurs under deformation, ferrite and austenite are coherent and have low energy. Stress fields are present around precipitates when these particles are coherent due to an increase between precipitates and glide dislocations. At the last stage of deformation there is no more coherence between ferrite and austenite and, a long softening occurs due to the softer ferrite phase.

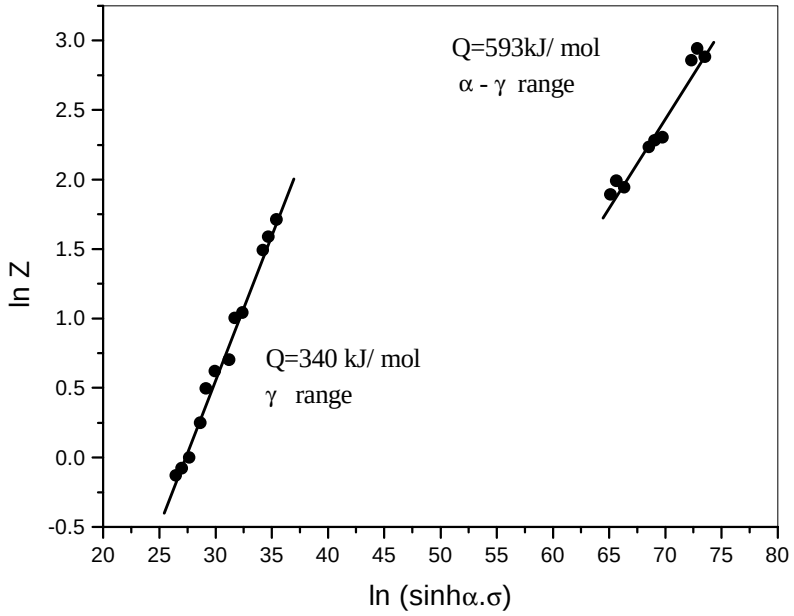

Figure 4 - Strain rate and temperature dependence, Zener parameter, for deformation in austenite and austenite–ferrite region.

4. CONCLUSIONS

The torsion tests performed, Figures 2 and 3, show flows curves that differs greatly with test temperature:

At high temperatures, from 1150 ^{0}C to 800 ^{0}C, the curves present a peak stress followed by a steady state which characterizes dynamic recrystallization behavior.

At temperatures ranging from 750 ^{0}C to 650 ^{0}C the curves presents no longer a peak stress, the curve raise to a maximum and stay constant at this value, this behavior characterizes dynamic recovery.

The flow curves below 650 ^{0}C change abruptly with strong work hardening to a hump and a later extensive softening, which can be related to the K-S mechanism of texture change.

The activation energy of deformation, Q, at hot deformation is 340kJ/mol, and at warm deformation is 593 kJ/mol.

REFERENCES

Briottet, L., Jonas, J.J, & Montheillet, F., 1996, Acta Metallurgica, vol. 44, pp.1665-1672.

Sellars, C. M., Tegart, W.J.McG., 1966, Mem. Sci. Ver. Met., v.63, p.731

Jorge Jr, A.M., 1991, MSc Dissertation, UFSCar, São Carlos, Brazil.

Honeycombe, R. W. K. , 1976, Transformation from austenite in alloy steels, Metallurgical Transactions A, vol. 7 A, pp.915-936.

Lourenço. N. J., Balancin. O., 1996, CONAMET IX / IBEROMET IV, Santiago - Chile, Outubro pp.39-51.

Stuart, H. & Wilson, W.G., 1981, Mechanical Working & Steels Processing, vol. 19, pp. 397-445.

Tanaka, T., 1995, Science and technology of hot rolling, Proceedings Microalloying 95, I.S.S., Pittsburgh, pp.165-181.