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INCREASING OF HOT WORKABILITY OF 1.3302HIGH SPEED STEEL

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Preliminary Note – Prethodno priopćenje

Laboratory investigation of hot workability of 1.3302 high speed steel was carried out and its improving was achieved. Hot compression tests for the determination of optimal soaking temperature as well as for the study of hot workability in temperature range 1150-850 °C, strain rates range 0,001-6 s^{-1} and applied strain up to 0,9 were performed. Microstructure of deformed specimen was analyzed. Apparent activation energies for hot working for upper and for lower temperature range were calculated. Onsets of dynamical recrystallization for applied deformation conditions on the basis of calculated strain hardening ratewere determined. Extending of hot working temperature range at its lower limit, i.e. down to 850 °C, by applying optimal soaking temperature was obtained.

Key words: 1.3302 HSS,hot compression, dynamic recrystallization, strain hardening rate

Poboljšavanje svojstava brzoreznog čelika 1.3302 u vrućem stanju. Data su laboratorijska istraživanja prerađivačkih svojstva brzoreznog čelika 1.3302 u vrućem stanju koji su doprinijeli poboljšanju tih svojstava. Izvedeni su pokusi vrućeg sabijanja za određivanje temperature zagrijavanja kao i prerađivačkih svojstva u temperaturnom rasponu 1 150-850 °C, brzinom deformacije 0,001-6 s^{-1} i stupnja deformacije do 0,9. Analizirana je mikrostruktura deformiranih proba.Izračunane su prividne aktivacijske energije za vruću preradu za gornje i donje temperaturno područje. Počeci dinamičke rekristalizacije za primijenjene uvjete deformacije utvrđeni su na temelju izračuna brzine deformacijskog očvršćavanja. Primjenjujući optimalno temperaturu zagrijavanja dobiveno je povećanje vrućeg radnog temperaturnog raspona na svojoj donjoj granici, odnosno do 850 °C.

Ključne riječi: 1.3302 HSS, vruće sabijanje, dinamična rekristalizacija, brzina deformacijskog očvršćavanje

INTRODUCTION

High speed steels (HSS), and also other tool steels, are in their applications subjected to high mechanical, thermal, tribological and chemical loads. HSS are highly alloyed with Cr, W, Mo, V, etc., i.e. carbide forming elements; the following types of carbides are usually present: MC, M_2C,M_6C, M_7C_3, and $M_{23}C_6$. During heating, soaking and hot deformation, various processes regarding the carbides take place in the steel, i.e. decomposition, dissolution, formation as well astheir growth and coarsening. The type of carbides, their quantity, morphology, shape and size depend on the chemical composition of steel and processing parameters, e.g. casting temperature, solidification rate, soaking temperature and time.Carbides in the steel improve hardness, strength and wear resistance. However, they also cause decreasing of hot workability, i.e. they narrow temperature range of safe deformation in comparison to other steels,[1-5]. The upper limit of the temperature working range is related to the occurrence of incipient melting of eutectics and phases with low melting point on grain boundaries as well as to grain growth. On the other hand,the lower limit of safe hot working range is related to precipitation of secondary carbides, characteristics of primary carbides in the matrix and/or on grain boundaries as well as to decreased recrystallization rate. Thus the microstructure of HSS consists of a martensitic matrix with ledeburitic and secondary carbides. However, to predict thebest hot working parameters and final microstructure, a detailed understanding of interactions between hot deformation behavior, softening mechanisms (recrystallization and recovery), and phase transformations is necessary, [5-9].

HSS 1.3302 is used for special tools such as tufting knives and loopers, slot cutters, blades, etc. Demands for hot rolling of profiles with small dimensions are expressed by the industry,which also leads to final hot rolling at lower temperatures as usual. In this paper, optimal soaking temperature for hot working of this HSS was investigated. Hot compression tests at various temperatures (also bellow 900 °C) and strain rates were also performed. Initial dynamic recrystallization (DRX) for selected strain rate and temperature was determined by means of strain hardening rate.

EXPERIMENTAL PROCEDURE

Hot workability of 1.3302HSS was examined using cylindrical hot compression tests. The cylindrically shaped specimens (Φ10 mm × 15 mm)taken from soft

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annealed square billet (100 × 100 mm) with chemical compositionare presented in Table 1.

Table 1 **Chemical composition of 1.3302 HSS / wt.%**

C	Cr	Mo	V
1,28	4,15	0,85	3,75
W	Si	Mn	Fe
12,9	0,045	0,40	Base

Hot compressiontests were carried outusing Gleeble 1500D thermo-mechanical simulator. Previously appropriate soaking temperature was determined using a new proposed procedure, [5].The use of this procedure can result in expanding of the safe hot working temperature range as well as in improved mechanical properties. Conditions for study of hot workability were as follows: temperature range 850–1150 °C, constant strain rates range0,001–6 s^{-1} and applied strain of 0,9.Test samples were heated at 3 °C s^{-1} to the soaking temperature and held there for 10 min. Afterwards they were cooled at 2 °C s^{-1} to the deformation temperature and held there for another 10 min before they were compressed. In order to determine the activation energies, the peak stress values were fitted to the empirical sine-hyperbolic equation, [5,7-14].

RESULTS AND DISCUSSION

Initial microstructure of soft annealed state, as taken from the supplied billet, consistsof ledeburitic and secondary carbides inserted in spheroidesed perlite matrix. Using the new procedure, the optimal soaking temperature was determined to be at 1180 °C. The useof this optimal soaking temperature prevents the growth of carbides during soaking which increasesthe hot workability, especially at a lower limit of the temperature range.

In this section, single hit stress-strain curves for 1.3302 are presented. Figure 1a illustrates the effect of temperature on the stress–strain curves at a constant strain rate of $\dot{\varepsilon}$ = 0,001 s^{-1}, where flow stress is decreasing with higher temperatures. All curves exhibit a rapid initial increase to the maximum stress, characterized by a peak, followed by a stress decrease to the steady state. This indicates that DRX acts as mainsoftening mechanism during deformation, [5-11]. Initiation of DRX can be identified from the change in the slope of a strain hardening ratecurve θ, [12,13] which is obtained by derivation of the flow stress σ and is calculated as:

$$\theta = \left(\frac{\partial \sigma}{\partial \varepsilon} \right)_{\dot{\varepsilon}} . \qquad (1)$$

Obtained results on derivation, where DRX initiates, are presented in Figure 2 foreach individual deformation condition.From both figures, it is clearly visible that with the decreaseof deformation temperature and the increase of strain rate,the initiation of DRX is shifted to higher stresses (Figure 2a), as well as to higher strains (Figure 2b). Especially at lower temperatures and lower strain rates,the initiation of DRX is shifted to slightly lower initial strains.

Another important feature that can be obtained from stress curves are peak stresses used to model deformation process. Values for the peak stresses for all deformationconditions were collected and are plotted in Figure 3. There is a clear falling trend of the peak stress values when the temperature is increased. As expected, peak stress values increase with higher strain rates at any given temperature.

The apparent activation energy for hot workingwasobtained using the following hyperbolic sine equation, [5-11,14]:

$$Z = \dot{\varepsilon} \exp\left(\frac{Q_{\mathrm{def}}}{RT} \right) = A \sinh^{n} (\alpha \sigma) \qquad (2)$$

where Q_{def} is the apparent activation energy for hot working determined from the peak stress, A and α are the material constants, n is the stress exponent $\dot{\varepsilon}$, $\dot{\varepsilon}$ is the strain rate, σ is the flow stress, T is the absolute temperature and R is the gas constant. The details for calculationof all constants are given elsewhere in [11]. Acti-

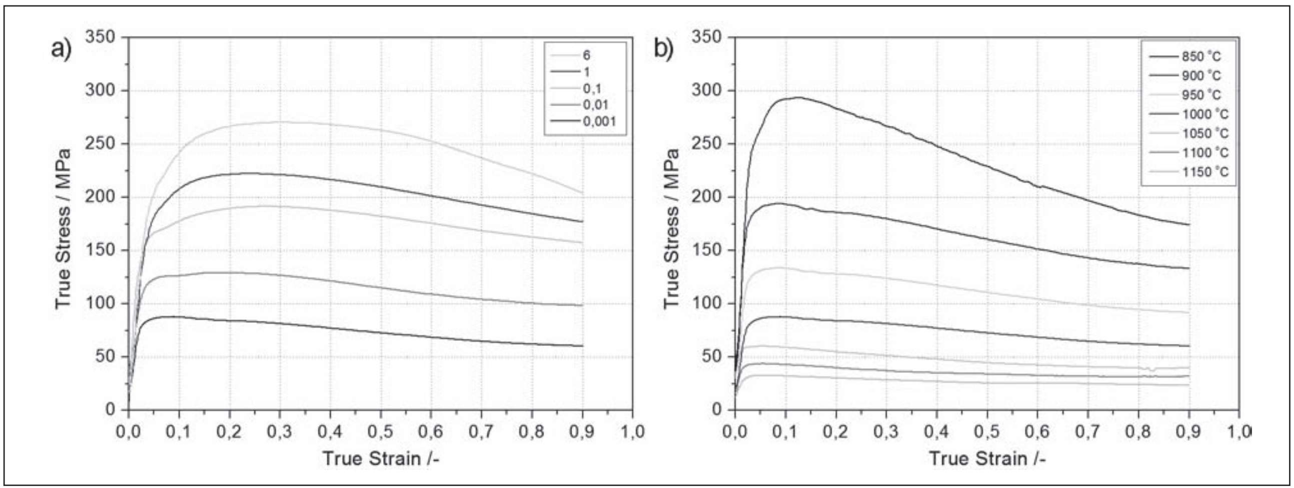

Figure 1 Stress–strain curves a) for temperature of 1100 °C and various strain rates, and b) for strain rate of 0,001 s^{-1} and various temperatures

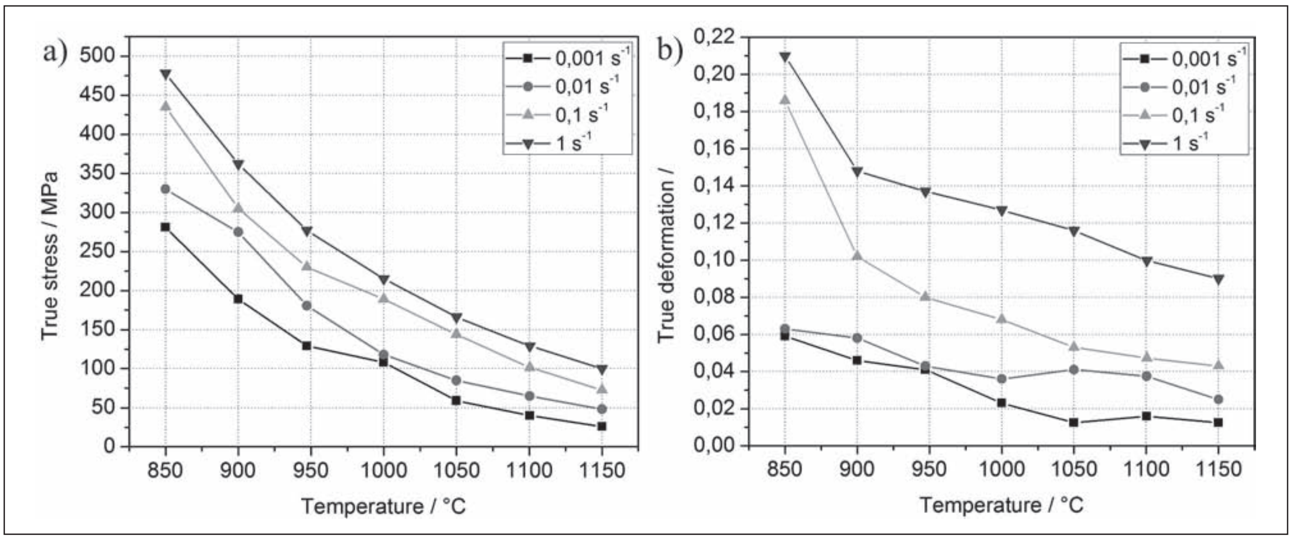

Figure 2 Strain hardening rate a) in dependence on temperature, true stress and strain rate, b) in dependence on temperature, strain (deformation) and strain rate

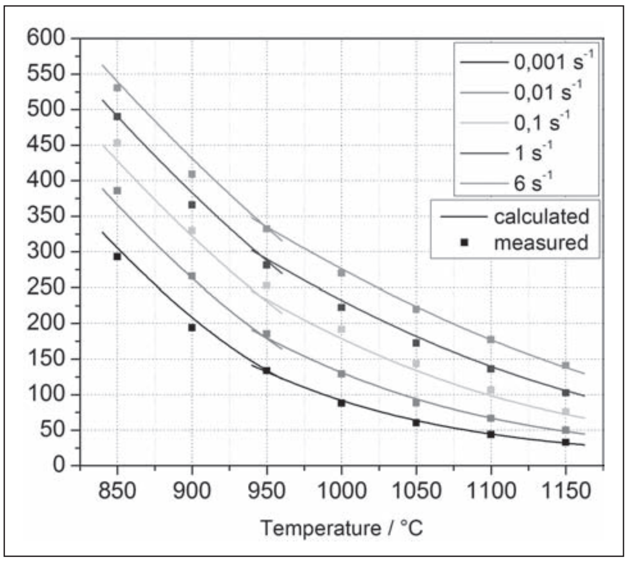

Figure 3 Peak stress versus temperature for different strain rates

vation energies and other constants of hyperbolic sine equation were calculated for two temperature rangesdue to the precipitation of secondary carbides bellow 1000 °C, [5,7]. For the lower temperature range, i.e. 850–950 °C,the obtainedvalues are:α = 0,005671 MPa^{-1}, n = 6,42, Q_{def} = 870 kJmol^{-1},while for the upper temperature range, i.e. 950-1150 °C, these values amount to: α = 0,00721 MPa^{-1}, n = 5,37 and Q_{def} = 606 kJ mol^{-1}.The comparisons between calculated (eq. 2) and measured peak stresses at various thermo-mechanical conditionsare given in Figure 3. Good agreement between experimental and calculated values for peak stresseswas obtained.

Figures 4a–4d show microstructures of the center of deformedsamples at various strain rates and deformation temperatures. Figures 4a and 4b depict the effect of the constantdeformation temperature at 1150 °C and strain rates at 6 s^{-1} and 0,001 s^{-1}, respectively.

The mixture of martensitic and retain austenitic matrix microstructure with fewlarge eutectic carbides is depicted in Figure 4a. Small eutectic carbides are dispersed on the grain boundaries. The mean size of recrystallized grains amounts to approximately18 μm. Figure 4b showslath shaped martensite matrix with dispersedsecondary and irregular eutectic carbides. Figures 4c and 4d depict the effect of constant deformation temperature of 850 °C, at strain rates of 6 s^{-1} and 0,001 s^{-1} onthe microstructure, respectively.On bothfigures, fine lath shaped martensite matrix is observed with dispersed small spherical and irregularly shaped coarse carbides. Lower safe deformation limit for HSS steels was previously 920 °C, [5]. However with use of the optimal soaking temperature no cracks were observed on deformed specimens at 850 °C. This is attributed to the determination of optimal soaking temperature. Furthermore, the microstructures confirm that the fraction of recrystallized grains is higher when the deformation temperature is increased. Similar results are noticedwhen the strain rate is lowered, which provides more time for DRX.These results comply with the findings of other authors, cf. [3, 5, 7, 10, 14]. The start of DRX and the small amount of recrystallized material volume is visible at highest strain rate (6 s^{-1}), Figure 4a.

CONCLUSION

Hot compression tests for 1.3302 HSS in wide range of deformation conditions were carried out. The optimal soaking temperature was assessed and the microstructure of deformed specimens was analyzed. The strain hardening rates were determined and the apparent activation energies for two temperature ranges were calculated.The following conclusions can be drawn:

- The optimal soaking temperature of 1180 °C extends safe hot working range, from 920 °C down to 850 °C. That supports industrial aims for hot rolling of profiles with smaller dimensions thanso far.
- When the strain rate is increased or the temperature is lowered, the apex of stress is shifted to higher strain.

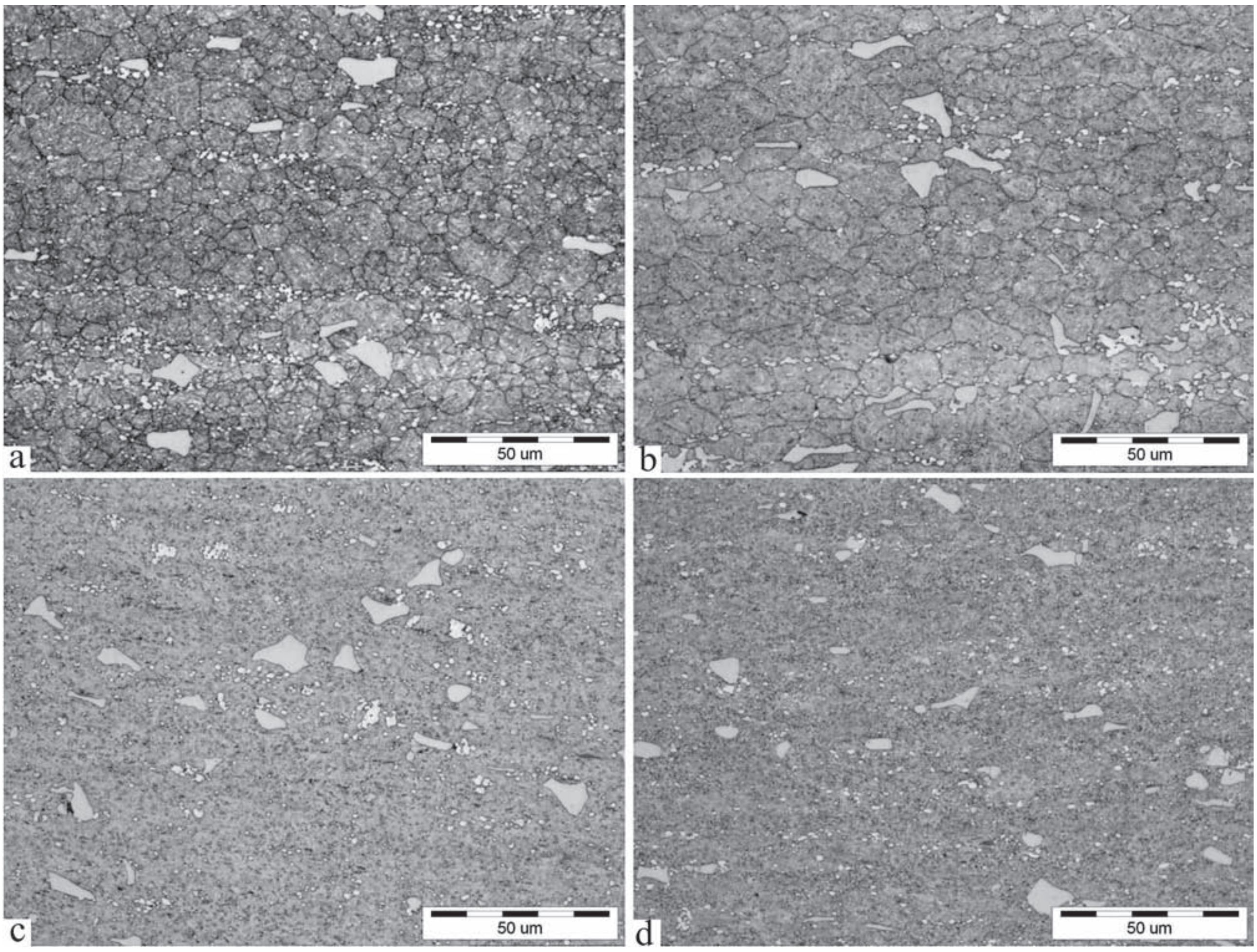

Figure 4 Microstructure in the middle of deformed specimendependent on the temperature and strain rate: a) 1150 °C, 6 s^{-1}, b) 1150 °C, 0.001 s^{-1}, c) 850 °C, 6 s^{-1}, d) 850 °C, 0.001 s^{-1}

- The apparent activation energy for temperature range 950–1150 °C amounts to 606 kJ mol^{-1}, while for lower temperature range, i.e. 850–950 °C, this value amounts to 870 kJ mol^{-1}. Strain values for the initiation of DRX increase with increasing strain rate and decreasing temperature.

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Note: The responsible translator for English language is Živa Fajfar, Bled, Slovenia