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INFLUENCE OF TESTING RATE ON LÜDERS BAND PROPAGATION IN NIOBIUM MICROALLOYED STEEL

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Using thermal imaging camera during tensile testing of low carbon and Nb microalloyed steel influence of testing rate on start of plastic deformation was investigated. The results showed that the onset of plastic flow is significantly different in Nb steel. When testing Nb steel, above the yield point (R_{eh}), Lüders bands formed and no change of temperature was recorded by increase of sample stretching force. Strain rate affects the propagation velocity of Lüders bands through the deformation zone.

Key words: microalloyed steel, thermography, plastic deformation, speed of Lüders bands

INTRODUCTION

Niobium microalloyed steels are low carbon steels with up to 0,05 wt/% Nb. The proper content of carbon and niobium and the appropriate parameters of thermomechanical working, especially in the final phase, ensure a decrease of ferrite grain size and improved properties of the rolled steel [1]. By austenisation, niobium carbide precipitates are dissolved and precipitate again at lower rolling temperatures [1].

Niobium is bound to hard carbide and carbonitride particles that are obstacles to the motion of mobile dislocations, affecting mechanical properties and the mechanisms of recrystallisation and recovery by hot working [1-2]. So far, only the effect of niobium precipitates on the deformation process was explained as inter-relation of deformation mechanisms, precipitation, recovery and recrystallisa-tion. For this reason, in this work, the effect of the presence of niobium in the steel on the start of the material plastic flow is investigated.

In the last few years, thanks to modern experimental techniques such as thermography and digital image correlation, the investigation of material behavior showed at start of plastic deformation a new phenomenon’s.

Thermography and measured changes of surface temperature in the deformation zone offer a clear image of material flow during the plastic deformation. So far, scarce thermographic investigations have shown that by some steels with clearly defined upper and lower yield stress, by slow static extension localized plastic deformation occurs [2-5].

This deformation is depicted as heat bands propagating along the specimen. Latest investigations connect the formation of heat bands with the Lüders bands [3-7].

Several parameters may affect the forma-tion and the propagation of Lüders bands along the deformation zone. In this work, the effect of testing rate on the formation, propagation, and temperature change on front of Lüders band is investigated.

EXPERIMENTAL WORK

Experimental specimens were taken from hot rolled 370 mm x 3 mm bands from low carbon steel and niobium microalloyed steels, with chemical composition given in Table 1.

Table 1 **Chemical composition / wt %**

Steel	C	Mn	Si	Al	Nb	N
Low carbon	0,13	0,77	0,18	0,02	-	-
Microalloyed	0,12	0,78	0,18	0,02	0,048	0,008

The test specimens were covered with a thin layer of top coat ensuring the uniform emissivity factor of f_{em} = 0,95. The top coat, which may influence the results of measurements, was selected after prelimi-nary investigations [8].

Static tensile tests were performed of the tensile testing machine Zwick 50 kN by elongation rates of 5 mm s^{-1}, 10 mm s^{-1}, 15 mm s^{-1} and 30 mm s^{-1}. By testing the relation force-elongation and the surface was filmed with the infrared camera VarioCAM M82910 with temperature recording sensitivity of 80 mK, calibrated on ambient temperature and fixed by angle 15° with respect to the observed specimen. The tests were carried out at room temperature.

EXPERIMENTAL RESULTS AND DISCUSSION

By all testing rates inhomogeneous defo-rmation occurred only in niobium steel in the zone A - B (Figure 1a).

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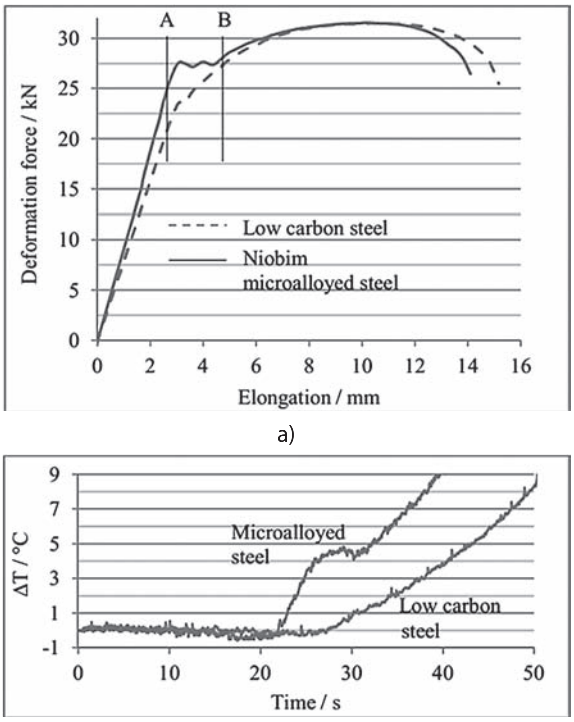

a)

b)

Figure 1 Temperature changes during stretching

By both tested steels and all elongation rates, the decrease of temperature was observed in the zone of elastic deforma-tion. In recent investigations the decrease of temperature was observed and it was denominated as thermoelastic effect [9,10].

Temperature drop depends of steel type and it may attain some centigrades. By end of elastic deformation, the temperature increased by both steels (Figure 1a). By equal deformation rate, in niobium steel the plastic flow starts earlier and it occurs in the zone of inhomogeneous deformation (Figure 1a and 1b).

First, the temperature increases, than it remains constant and after the point B (Figure 1a) it increases again. In the carbon steel the temperature increases continuously, figure 1 b). By niobium steel, this behavior was observed by all testing rates (Figure 2).

By start of plastic deformation, the tempe-rature is increased in part of deformation zone, bright area Figure 3. The increase of temperature to a constant level propagates with formation of a band at the angle of about 45^{o} through the deformation zone and it is related to the formation of Lüders bands [5,6].

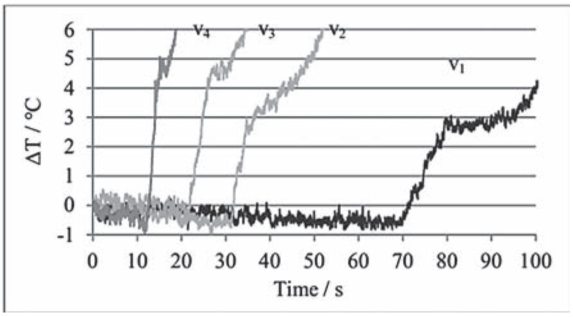

Figure 2 Effect of deformation rate on the initial of plastic flow

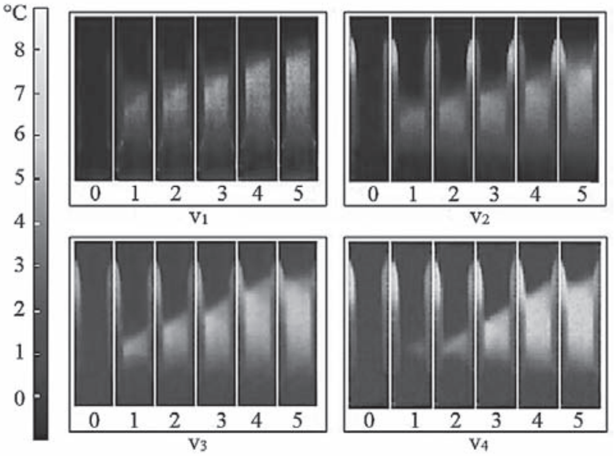

Figure 3 Propagation of Lüders bands

On thermographs, the formation of Lüders bands appears as thermal fronts shifting along the investigated specimen length up to a limit deformation of the tests specimen, Figure 3. Then, the stress and deformation start to increase continuously up to tensile strength level (R_m).

By increase of deformation rate, the time of formation and propagation of Lüders band is decreased. The effect of deformation rate on the formation and propagation of Lüders bands is depicted in Figure 2, also. In microalloyed steel, the nucleation of Lüders bands can be ascribed to the delay of motion of mobile dislocations caused by niobium precipitates.

The increase of temperature starts in the point 1 after the limit of proportionality is achieved with simultaneous elastic and plastic deformation. The number of grains in the examined specimen is very great, probably $>10^9$. The glide plane in ferrite is (011). The average angle of this plane and of the acting tensile stress in the tensile specimen is 45^{o}. Precipitates cut the dislocation line in segments that by sufficient stress are surmounted with dislocation climb, Figure 4.

The accumulation of mobile dislocation is not a direct effect of precipitates, but due to the content of vacancies which is constant. For the climb of every dislo-

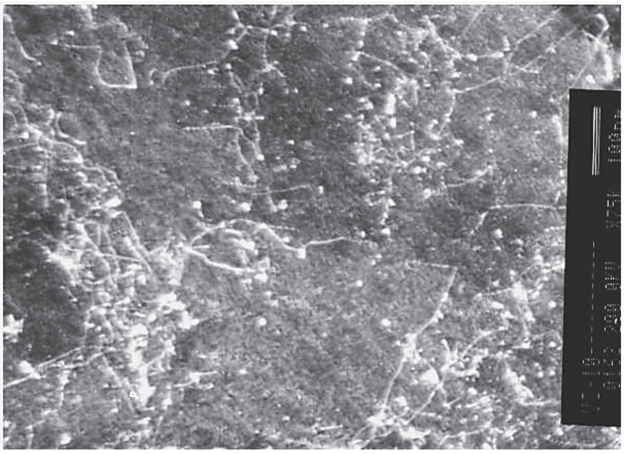

Figure 4 Precipitates and dislocations in the niobium steel

cation segment a vacancy is required. For this reason, a greater number of vacancies are necessary for motion of dislocations segments which number is greater by smaller spacing of precipitates.

When reaching a sufficient stress, in the part of metal lattice with suited stress related to the shape of the precipitates, rsp. probably the glide and climb component of acting stress, the glide of mobile dislocations is triggered and generates the Lüders bands. She is fully formed in point 2, Figure 5. In this moment, the critical stress is achieved for start of glide and climb that continue by lower stress and produce the inhomo-geneous deformation stress on the diagram stress deformation. Elastic strain on one side of Lüders band gradually becomes the state of complex triaxial stress, which leads to shifting the band away from itself. In this way, gradually the whole sample deforms by a certain amount of deforma-tion. Once the entire sample is deformed for that specific amount of deformation and Lüders bands is propagated through the whole length of the sample, then begins a homogeneous plastic deformation of the sample.

On thermograms, Figure 3, it is clearly seen that Lüders bands glide across the width of the deformation zone (the width of the tested sample). On thermo-grams, Figure 3, it is evident that the Lüders bands glide across the width of the deformation zone and the width of the test samples.

The results of investigations of formation and propagations of Lüders bands in some references suggest a constant band boundary temperature, lower behind it and constant in the zone of inhomogeneous deformation [6].

On all thermographs and all deformation rates the temperature was measured ahead and behind the Lüders band front (Figure 5), on the point of bands nucleation and on the characteristic points of inhomogeneous deformation (Figure 5b). The highest temperature was found on the section A - A at the Lüders bound front.

The change of temperature on the Lüders band front is related to the deformation front and parallel ΔT_{max} is increased as well.

If the thermoelastic effect is considered [9,10] and lowering of temperature by elastic deformation in the zone of the Lüders band nucleation, point 1 to 2, the increase of temperature is 4 to 6 °C. By greater rate, the increase of temperature is greater (Figure 2) and the maximal change of temperature at the front of Lüders bands ΔT_{LLmax} increases by propagation of Lüders bands, as well. Up to points 2 and 5, it increases by $\Delta T_{LLmax} = 1 – 1,5$ °C, Figure 6. The results suggest that by increase of elongation rate, the rate of propagation of Lüders bands increases linearly (Figure 7).

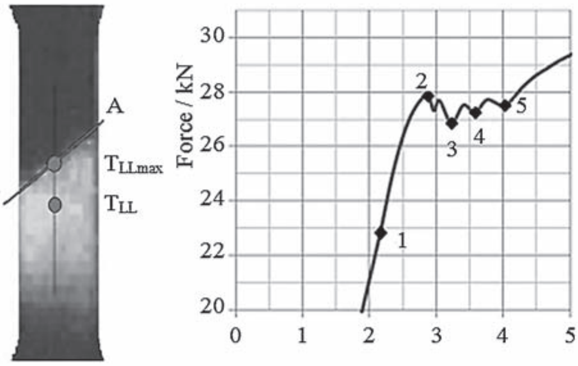

Figure 5 Increase of temperature during deformation in specific points

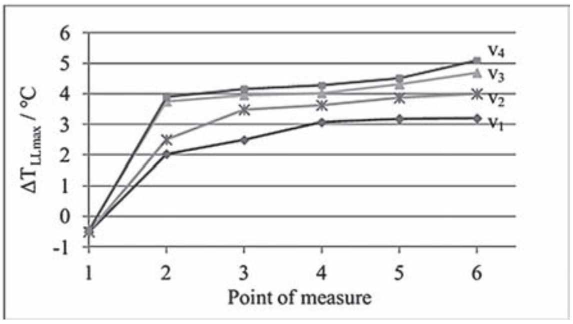

Figure 6 Temperature change of Lüders bands front

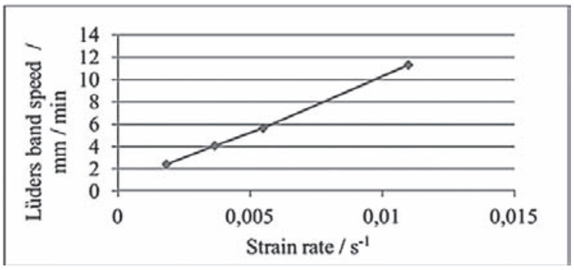

Figure 7 Lüders band propagation rate versus strain rate

A similar effect was observed by some carbon steels by different deformation rate [4,5]. The increase of propagation rate can be connected with the loading rate as well as with increasing of strain rate. The speed of formation of the deformation zone is increased and the critical stress required for the propagation of Lüders bands is achieved earlier.

The temperature was assessed behind the Lüders band, ΔT_{LL} Figure 5a). By band formation the temperature is ΔT_{LLmax}. After start of band propagation, at the front of the Lüders band ΔT_{LLmax} increases and it is higher than ΔT_{LL}. ΔT_{LL} increases as behind the Lüders band, elastic and plastic deformation occurs.

CONCLUSIONS

Research results have shown that the start and progress of deformation of niobium microalloyed steel with cold deformation significantly different compared to the same steel without niobium. It was found that the steel in the range of elastic deformation for all test speed leads to lowering the temperature, or the occu-rrence of thermoelastic effect. The emergence Lüders band associated with the braking movement of dislocations in the arrays of niobium precipitates. In the crystal structure with the highest potential energy is formed front deformed and non-deformed structure or Luders bands that propagates through whole length of the deformation zone.

On the front Lüders band there is a local increase in temperature. Thermography indicated that the nucleation and propa-gation of Lüders bands is accompanied by local changes of temperature, and that the increase of temperature is related to the local level of plastic strain. Maximum temperature rise at the front of Lüders band is 1 – 1,5 °C.

Strain rate has a significant impact on the initiation and course of plastic defo-rmation. The increase in strain rate, due to increase in testing rate, leads to an increase in the speed of Lüders band propagation. Also the increase of the strain rate leads to greater temperature changes at the Lüders band front.

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