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Influence of strain rate on stress changes during Lüders bands formation and propagation

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Influence of strain rate on stress changes during Lüders bands formation and propagation

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Abstract. Characterization of the Lüders bands that occur in niobium microalloyed steel is carried out in different points of their formation and propagation. During static tensile testing infrared thermography is simultaneously used to record temperature changes and digital image correlation to determine the strain amounts in specific points of Lüders bands formation and propagation. Temperature changes which present stress changes were taken at the different strain amounts 0.005 mm/mm, 0.013 mm/mm, 0.026 mm/mm and 0.032 mm/mm. Performed static tensile tests showed the influence of different strain rates $1.8 \cdot 10^{-3}$ s^{-1}, $7 \cdot 10^{-3}$ s^{-1} and $1.85 \cdot 10^{-2}$ s^{-1} on the stress changes during Lüders bands formation and propagation. In different specific points such as Lüders band front, behind the Lüders band front (deformed area) and in front of the Lüders band front (undeformed area) tests were carried out. The studies revealed maximum stress changes behind Lüders band front and their increase with increasing strain rate. At the highest strain rate in the point of maximum stress behind the Lüders band front the greatest temperature changes was measured.

1 Introduction

Niobium microalloyed steels are low carbon steels that show the appearance of inhomogeneous deformations, i.e. Lüders bands [1,2].

It is well known that during the plastic deformation the release of heat energy is manifested as a temperature changes on the sample surface. Therefore, infrared cameras are often used to determine the temperature changes during deformation process [3,4]. In this way, it is possible to detect temperature changes and/or stress changes when Lüders band appear during cold deformation.

Thermography and digital image correlation has shown as suitable methods to detect Lüders bands in different type of steels [5] and aluminium alloys [6]. Combined these methods allowed a precise characterization of the Lüders bands and provide qualitative and quantitative analysis of Lüders bands formation and propagation at any point in the deformation zone [7].

Lüders band are clearly observed in studies on low carbon steels and niobium microalloyed steels during cold deformation at different strain rates. It was noticed that the velocity of the Lüders band propagation increase with the strain rate during cold deformation [2,8].

The contribution of this paper is determination of strain rates effect on stress changes during Lüders bands formation and propagation. Temperature changes will show stress changes in different points of Lüders bands formation and propagation at different strain rates.

2 Experimental

Samples were taken from hot rolled microalloyed strip with addition 0.6% of niobium. Tensile test is carried out on the static tensile machine EU 40mod with a nominal force value 400kN at three different strain rates $1.8 \cdot 10^{-3}$ s^{-1}, $7 \cdot 10^{-3}$ s^{-1} and $1.85 \cdot 10^{-2}$ s^{-1} at room temperature. The samples used had the original gauge length of 45 mm, width of 20 mm and thickness of 3 mm. Chemical composition is given in table 1.

Table 1. Chemical composition of niobium microalloyed steel [wt.%].

	C	Mn	Si	P	S	Al	Nb	N
Nb-steel	0.11	0.50	0.10	0.017	0.020	0.018	0.060	0.0083

The temperature changes on the samples were observed with an infrared camera. Infrared camera (VarioCAM M82910) with temperature sensitivity 80 mK is focused on one side of the sample surface. Uniform emissivity factor of black matte coating used for thermography was 0.95.
Strain amounts were determined with digital image correlation using digital camera Panasonic HDC-SD9 over entire deformation zone.

3 Results and discussion

Thermographic tests of niobium microalloyed steels simultaneously with static tensile tests were performed to determine temperature changes in the deformation zone during Lüders band appearance. At the same deformation amounts, the temperature changes can be observed as a stress changes in the deformation zone.

During static tensile tests proportionality limit (P) and points A, B, C, D are determined, figure 1. Up to proportionality limit (P) only elastic deformations take place in niobium microalloyed steel. By reaching proportionality limit to point D, elastic and plastic deformation occur. After point D only plastic deformation occurs in the material.

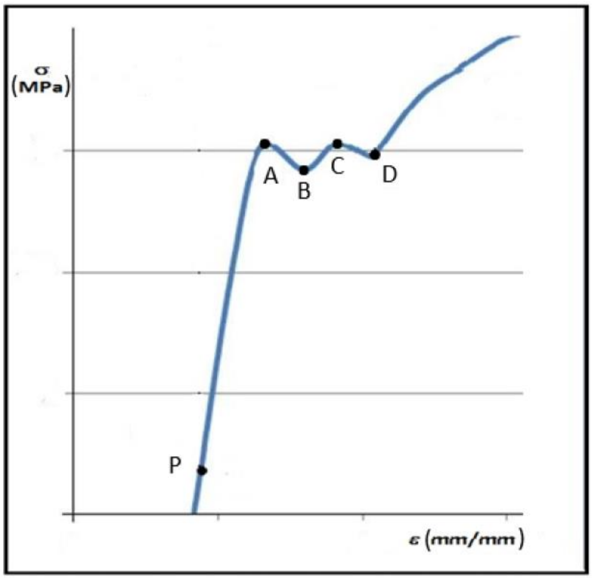

Figure 1. The area of inhomogeneous deformations during static tensile test.

Achieved strains were measured with digital image correlation in the points A, B, C, D. At the point A there was a strain of 0.005 mm/mm and at the point D strain was 0.032 mm/mm which means that the propagation of the Lüders bands through the deformation zone from point A to point D increase strain amounts, figure 1.

Temperature changes are determined with thermographic tests of niobium microalloyed steels during static tensile tests in the deformation zone. Temperature changes indicate a stress changes during deformation. Thermographic measurements have established that the Lüders band forms in the area from proportionality limit (P) to point A, figure 2. From point A to point D, Lüders band propagates through the deformation zone. Figure 1 shows the occurrence of inhomogeneous deformations in this area.

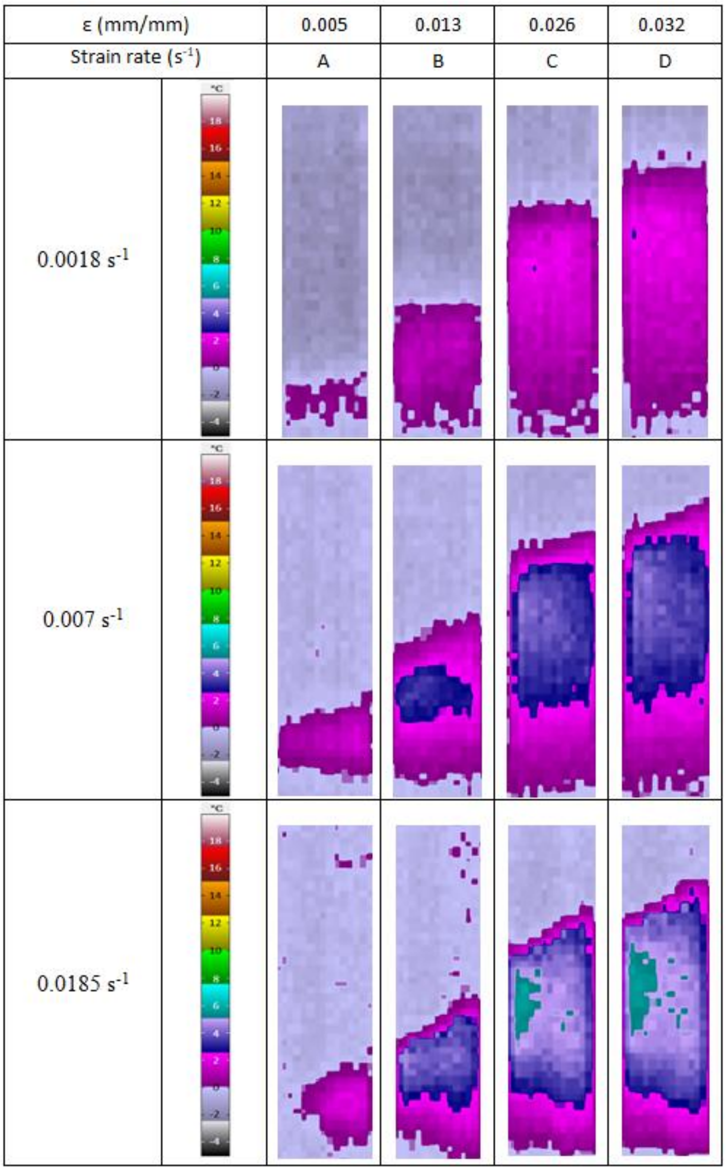

Figure 2. Lüders band propagation at various strain rates and strain amounts.

Tests were carried out at three different stretching rates in which strain rates of $1.8\cdot10^{-3}$ s^{-1}, $7\cdot10^{-3}$ s^{-1} and $1.85\cdot10^{-2}$ s^{-1} were achieved. The appearance of the Lüders band was observed at each strain rate. At all strain rates Lüders band is formed and propagates through the deformation zone.

Quantitative thermographic analysis during Lüders band propagation through the deformation zone showed stress changes at points A, B, C and D. The increase of the stress with Lüders band propagation from one end of the sample to the other end of the sample through the deformation zone is observed by increasing strain amounts at the same strain rate. It is clear visible higher stress changes behind Lüders front at higher strain rates, figure 2.

In order to determine the influence of strain rate on the stress changes during Lüders band propagation through the deformation zone, the stress changes in the characteristic points of the deformation zone were determined. The measurements were performed in three characteristic points: in front of the Lüders band front (R_1), on the Lüders band front (R_2) and in the area of maximum temperature changes or stress changes behind the Lüders band front (R_3), figure 3.

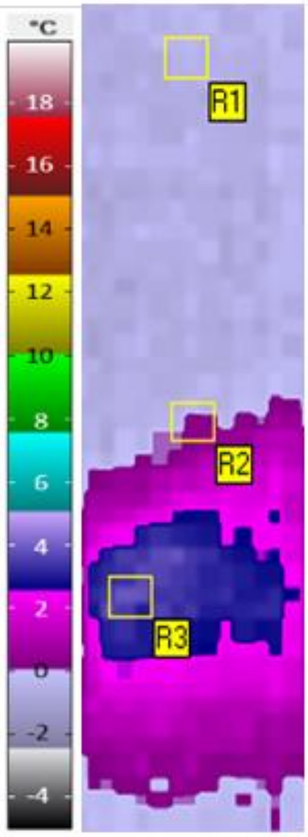

Figure 3. Thermographic measurement in characteristic points during Lüders band propagation.

In the area in front of the Lüders band front, there are no stress changes (R_1). There are also no stress changes in the area in front of the Lüders band front (R_1) by increasing strain rate. On the Lüders band front (R_2) was not observed stress changes during Lüders band propagation. There are certain changes with the change of strain rate. The greatest stress changes were found behind the Lüders band front (R_3). These changes are more pronounced at higher strain rates. At the lowest strain rate (0.0018 s^{-1}), behind the Lüders band front (R_3), no stress changes were observed during Lüders band propagation. The increase of the strain rates (0.007 s^{-1} and 0.0185 s^{-1}) showed an increase of stress changes during Lüders band propagation, figure 2. The greatest stress changes behind the Lüders band front (R_3) were obtained at the highest strain rate (0.0185 s^{-1}). The obtained maximum stress changes with the strain rate changes behind the Lüders band front are shown in figure 4.

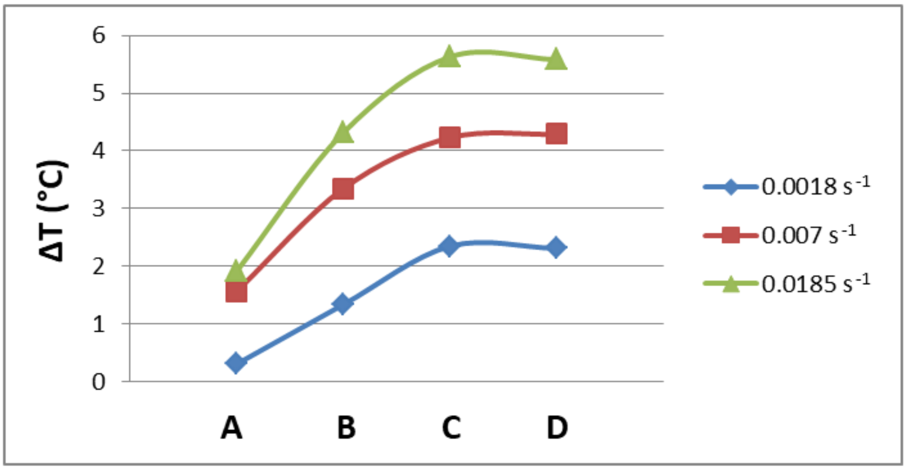

Figure 4. Maximum stress changes behind the Lüders band front with change of strain rate.

Figure 4 clearly shows that the temperature changes, i.e. stress changes behind the Lüders band front are the greatest at the highest strain rate. At the same strain rate, stress increase during Lüders band propagation through the deformation zone. This phenomenon was not previously found in niobium microalloyed steel.

Futher microstructural studies will research what is the reason of stress increase during Lüders band propagation.

4 Conclusion

The conducted tests have shown that the strain rate affects stress changes at the start of plastic flow during cold deformation in niobium microalloyed steel.

Inhomogeneous deformations occur at the start of plastic flow of material. Lüders band appearance and propagation are related with inhomogeneous deformations. It was found that the Lüders bands appear at all strain rates.

At the same strain rate, certain stress increase during Lüders band propagation through the deformation zone was determined. These stresses increase with increasing strain rate at the same strain amount.

Further research on the effect of microstructure will show the influence of microstructure homogeneity on stress changes at the start of plastic flow.

Acknowledgment

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