The influence of niobium content and initial microstructure of steel on the occurrence of Lüders band at the start of the plastic flow during cold deformation

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Abstract. In this paper, the results of a research on influence of niobium and initial microstructure on start of plastic flow of a material and formation of Lüders bands during cold plastic deformation in niobium microalloyed steel are presented. Research was carried out on hot rolled strips from low carbon steel and three steels with the same base chemical composition but with different amount of niobium: 0.035% Nb, 0.048% Nb, 0.060% Nb. Niobium microalloyed steel strips are rolled with selected parameters of thermomechanical treatment and additionally heat treated with the goal of achieving inhomogeneous microstructure. Static tensile testing was performed on samples, while simultaneously being recorded with thermographic camera. The results of thermographic measurements were analysed with software package Irbis 3 professional. The initial microstructure is tested for all samples. During the start of plastic flow in all microalloyed steel samples, with fine-grained homogeneous microstructure, inhomogeneous deformations are created. These were not found on samples which do not contain microalloying element niobium. In area of inhomogeneous deformations, Lüders bands are formed and propagate through the deformation zone. Lüders band was not found in microalloyed steels with coarse grain. The tests show that the addition of micro-alloying element niobium affects Lüders bands formation but the content of niobium in steel has no effect on the appearance of the Lüders bands. Additionally, it was found that the initial microstructure has a great influence on Lüders bands occurrence.

1 Introduction

In recent years, inhomogeneous deformations are intensively investigated at the beginning of the plastic material flow during cold deformation [1]. It has been found that they are associated with the occurrence of the Lüders bands [2-4].

They have not yet been given a realistic explanation of why Lüders bands occurs and which are the influential parameters for their occurrence and propagation. Some authors associate them with precipitates of alloying and micro-alloying elements [4-6]. Other authors associate them with the initial microstructure, primarily with grain size and homogeneity of microstructure [5-10]. The influence of strain rate is also extensively investigated [4,10-12]. Today, thermography has found its application [13-14] of studies of stress changes at the appearance and propagation of the Lüders bands.

This paper presents the results of detailed research on behavior hot-rolled strip of thickness 3 mm with different contents of niobium and different initial microstructure at the beginning of plastic flow during cold deformation.

2 Materials and methods

Four types of steels were selected for this study: low carbon steel and three steels with the same base chemical composition but with different amount of micro-alloying element niobium 0.035%, 0.048% and 0.060%, Table 1.

Table 1. Chemical composition of steels [wt.%]

	C	*Mn*	Si	*P*	S	*Al*	*Nb*	*N*
1	0.13	0.77	0.18	0.010	0.019	0.020	0.000	0,0080
2	0.09	0.75	0.05	0.018	0.014	0.020	0.035	0.0081
3	0.12	0.78	0.18	0.011	0.018	0.020	0.048	0.0080
4	0.13	0.70	0.14	0.018	0.014	0.040	0.060	0.0081

In this research, samples from hot-rolled strip with thickness of 3 mm with different contents of niobium and different initial microstructures were taken. Steels with 0.00% and 0.048% of niobium are rolled in industrial conditions in 3 mm thick strip of hot rolled steel and 0.035% and 0.060% Nb steels are rolled in semi-industrial conditions with thickness of 3 mm. Thermomechanical treatment was carried out on all niobium microalloyed steels whit resulted in a fine-grained ferrite-pearlite microstructure. Steels 2 and 4 have been cooled at various rates after the thermomechanical treatment in order to achieve changes in microstructure homogeneity and grain size. Steel 3 was heated at 900 °C and air-cooled. The static tensile test was performed on the Zwick 50 kN at stretching rate of 5 mm/min.

3 Results and Discussion

The obtained diagrams of Force-Elongation curves are shown in Figure 1.

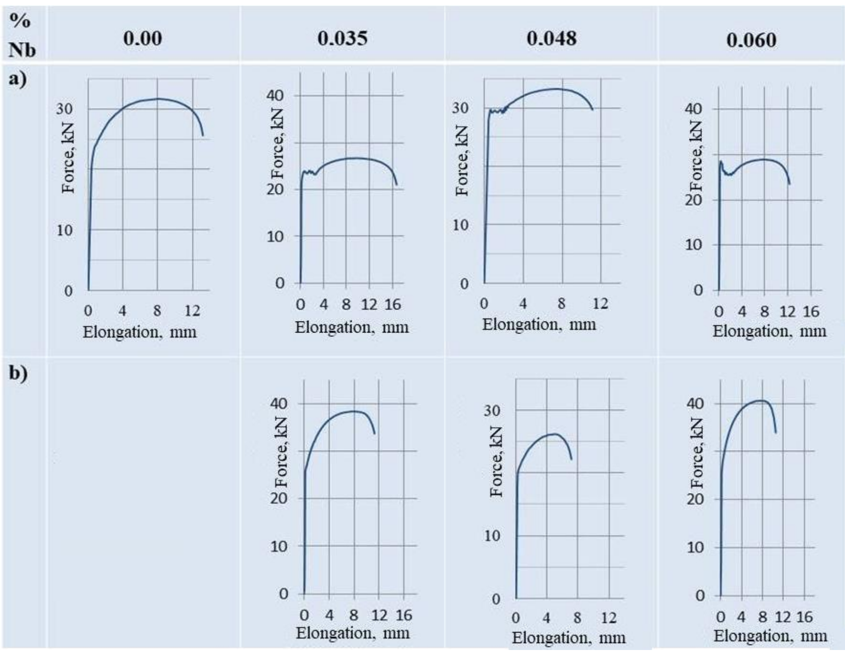

Figure 1. The appearance of inhomogeneous deformations during static tensile tests

It is clearly apparent that the steel without niobium did not have pronounced transition from elastic to plastic region and no inhomogeneous deformations at the beginning of the plastic flow. Samples containing the different content of micro-alloying element niobium and homogeneous fine-grained microstructure have a clearly pronounced proportionality limit (Rp) and have the appearance of inhomogeneous deformations at the beginning of the plastic flow. Steels with the same base chemical composition and different initial microstructure show different behaviors.

Metallographic microanalysis of rolled strips was performed. The obtained results are shown in Figure 2.

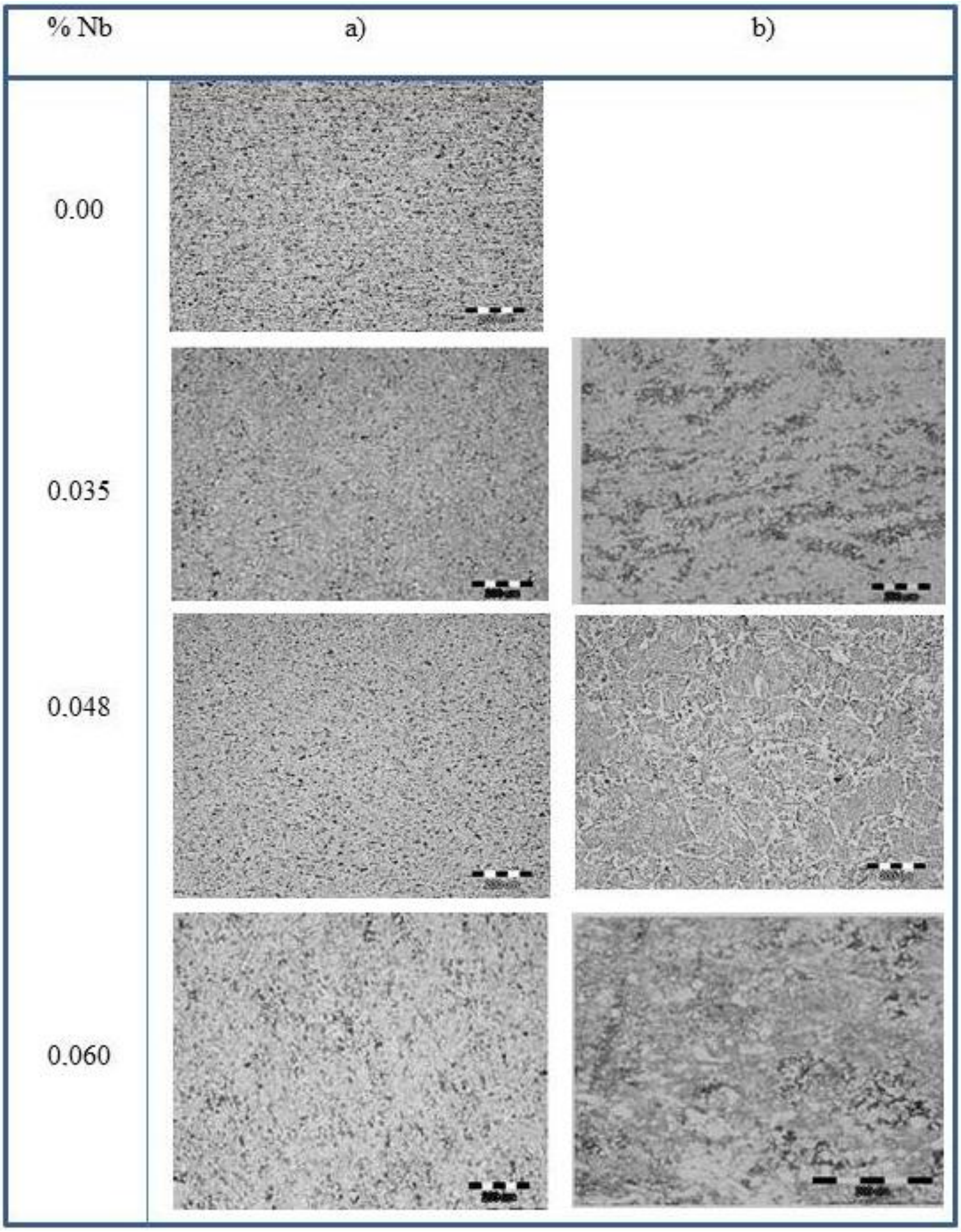

Figure 2. The initial microstructure of investigated steels:
a) After thermomechanical treatment and air-cooled
b) After rolling cooled at different rates

Figure 2 clearly shows that hot rolled strips (a) have a homogeneous fine-grained microstructure. The steel strips (b) with 0.035% and 0.060% Nb, are cooled on different temperatures and at different cooling rates. The steel strips (b) with 0.048% Nb, which was subsequently heated and cooled, have a coarse-grained inhomogeneous microstructure.
Thermographic measurements were also carried out simultaneously with static tensile test. Black matte coating Lechsys 29141 was applied on samples for thermographic tests.
Thermographic measurement was performed using Vario CAM® M82910 thermographic camera. The analysis of the measured results was carried out by Irbis 3 Professional software package. Stress changes have been established during deformation. Figure 3 shows thermograms of all tested samples.

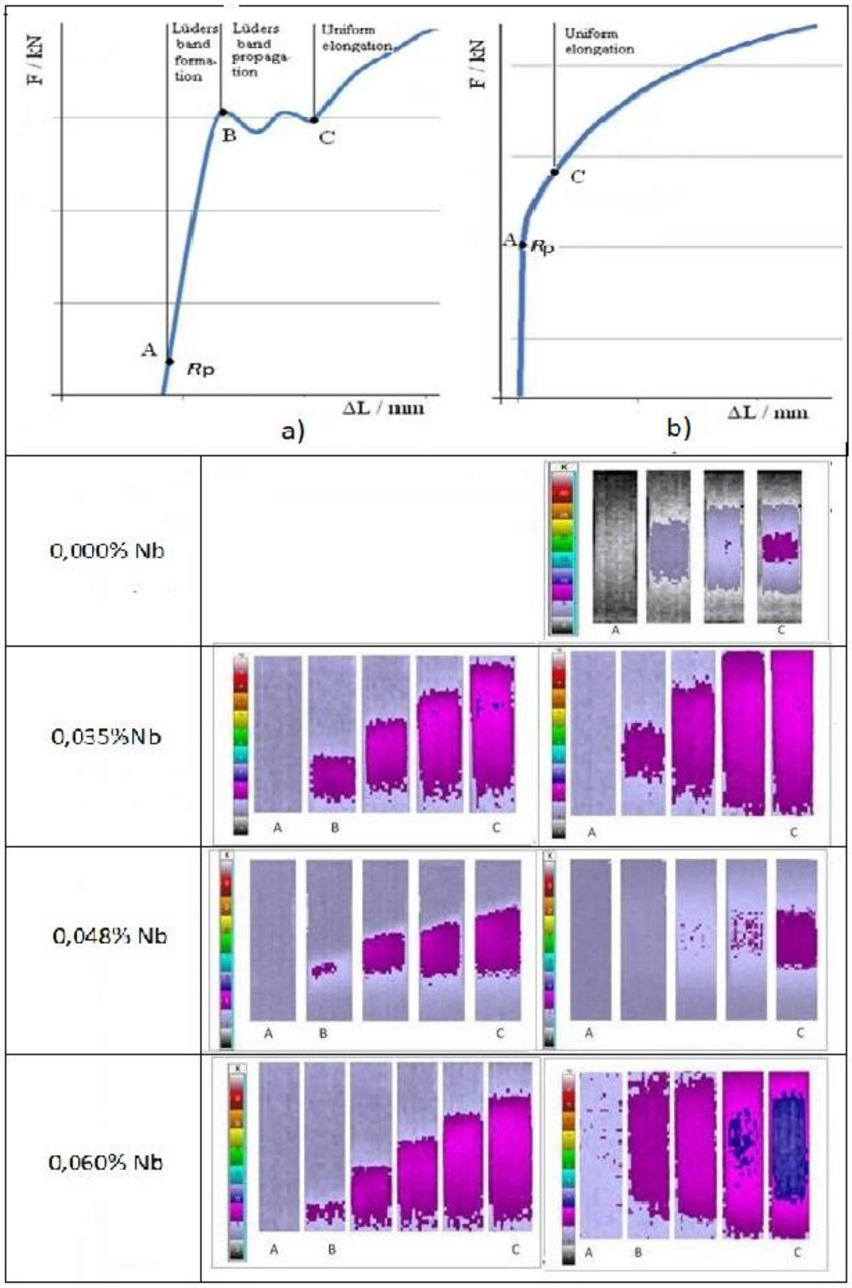

Figure 3. Thermograms of tested samples:
a) with the appearance of Lüders band, b) without appearance of Lüders band

Thermographic analysis has shown that in the area of non-homogeneous deformations are formed Lüders bands. In all three niobium microalloyed steels with homogeneous fine-grained microstructure (a), after reaching proportionality limit, point A, Figure 3, Lüders band formation and propagation begins from one end of the sample to the other end of the sample. The Lüders band is formed up to point B and propagates through the deformation zone, point C. Then, in the formed deformation zone, plastic deformation takes place until reaching tensile strength (Rm).

In the low carbon steel without niobium and all steels with niobium but having with a inhomogeneous microstructure, Figure 3, (b), no Lüders band were formed. After reaching proportionality limit, stresses are concentrated in the deformation zone and increase with the stretching force increase, from point A to C Figure 3.

Changed content of niobium has no effect on the appearance of the Lüders bands.

The reason why no niobium microalloyed steels has no occurrence Lüders band is related to the size and distribution of niobium precipitates. It has been shown that in the steel micro-alloyed with 0.048% Nb, Figure 3 a) size is niobium precipitates is 10 nm and the arranged in strings, while niobium precipitates in steel with the same content of niobium which was subsequently heated, Fig. 3 b) are 60nm [6-11].

4 Conclusion

The investigations have shown that the Lüders bands appear in the niobium micro-alloyed steel at the beginning of the plastic flow in cold deformation. For steel of the same base composition but without niobium and with homogeneous fine-grained microstructure, Lüders bands have not formed.

In the low-carbon steel, the addition of the micro- alloyed element niobium leads to the appearance of Lüders bands, but the content of the niobium in the steel does not affect the appearance of the Lüders bands.

It was also found that niobium microalloyed steels with inhomogeneous microstructure at the beginning of plastic flow during cold deformation, Lüders bands have not formed. This is related to the size of niobium precipitates.

Further research on microstructures, crystal grain orientation and size and distribution niobium precipitates, is needed to explain forming and propagation of the Lüders bands with cold deformation niobium microalloyed steel.

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