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**Coexistence of material science and sustainable technology in
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Sisak, May 15th-17th, 2019

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**EFFECT OF SUBSEQUENT HEATING ON THE MICROSTRUCTURE AND
MECHANICAL PROPERTIES OF Nb MICROALLOYED STEEL**

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Original scientific paper

Abstract

Effect of subsequent heating on the microstructure and mechanical properties of hot rolled niobium microalloyed steel was researched in this paper. Low carbon steel was microalloyed with 0.048 % niobium and it was heated at 1150 °C followed by cooling in the air. Researches were performed on two types of samples: low carbon steel microalloyed with niobium and subsequently heated microalloyed steel in the rolling direction as well as in the direction perpendicular to the rolling direction. Mechanical properties of all samples were determined by the static tensile test at testing rate of 5 mm/min. After that their microstructure was observed by scanning electron microscope. Results have shown a significant effect of subsequent heating on the microstructure, i.e. grain size as well as on the mechanical properties.

Keywords: *subsequent heating, niobium microalloyed steel, microstructure, mechanical properties*

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INTRODUCTION

The microalloyed steels nowadays are used for wide applications, such as constructions, automotive industry and shipbuilding. They are achieved by means of a suitable combination of chemical composition and thermomechanical treatment parameters. The aim of microalloying of steels is to ensure better mechanical properties and/or resistance to atmospheric corrosion than conventional carbon steels. This enhancement of properties may be achieved by dispersed precipitates that are obtained by addition of niobium, titanium, vanadium or aluminum. Namely, it is known that these elements form stable nitrides, carbides or carbonitrides [1-4]. The phases available in the microstructure of steel are determined by solidification and subsequent processing, such as hot or cold working,



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Sisak, May 15th-17th, 2019

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heat treatment and solid-state phase transformation as well as by chemical composition [5,6]. In this work niobium has been chosen as microalloying element since it significantly improves the mechanical properties and reduces final ferrite grain size. Refinement of microstructure, in terms of reduced grain size offers possibilities for increasing both strength and ductility [7,8].

MATERIALS AND METHODS

In this work, effect of subsequent heating on the microstructure and mechanical properties of hot rolled niobium microalloyed steel was studied. Chemical composition of studied steel is given in Table 1. It can be seen that low carbon steel was microalloyed with 0.048 % niobium and that 0.008 % of nitrogen is present. Namely, niobium is known as strong carbide and carbonitride forming element. By the formation of niobium carbides or niobium carbonitrides it may be achieved precipitation strengthening, grain refinement and control of transformation temperature. Also, the possible embrittlement caused by nitrogen is minimized in that way [1,4]. Steel of given composition was heated at 1150 °C followed by cooling in the air with purpose to obtain the bigger size of niobium precipitates that effects cold deformation flow and stress distribution in the deformation zone.

Table 1. Chemical composition of studied Nb microalloyed steel

| Element | C | Mn | Si | P | S | Al | Nb | N |
|---------|------|------|------|-------|-------|------|-------|-------|
| Wt.% | 0.12 | 0.78 | 0.18 | 0.011 | 0.018 | 0.02 | 0.048 | 0.008 |

Therefore, investigations were performed on two types of samples: low carbon steel microalloyed with niobium and subsequently heated microalloyed steel. Mechanical properties of all samples were determined by the static tensile test at testing rate of 5 mm/min at room temperature on the universal tensile testing machine Zwick 50kN. Tested samples were of rectangular cross-section taken in the rolling direction and in the direction perpendicular to the rolling direction from hot rolled strips with 3 mm thickness. For microstructural observations, samples were metallographically prepared by standard procedure at Buehler PHENIXBETA GRINDING/POLISHER and etched in nital reagent. After that, their microstructure was observed by scanning electron microscope TESCAN VEGA 5136MM.

RESULTS AND DISCUSSION

Mechanical properties of Nb microalloyed steel were determined by static tensile test at testing rate of 5 mm/min. Figure 1 shows force-elongation diagrams of Nb microalloyed steel tested in the rolling direction (Figure 1a) and in the direction perpendicular to the rolling direction (Figure 1b). It can be seen very similar curves for both test directions. They

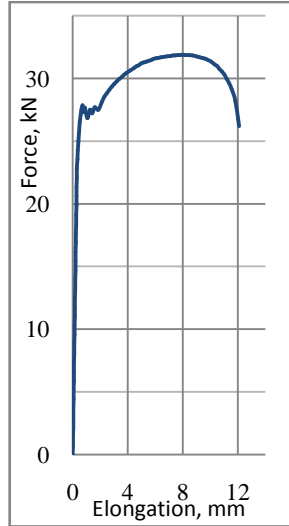


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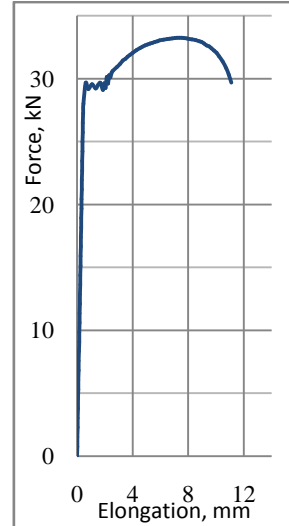
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show that after reaching the yield stress, values of force decrease and oscillated for one period.



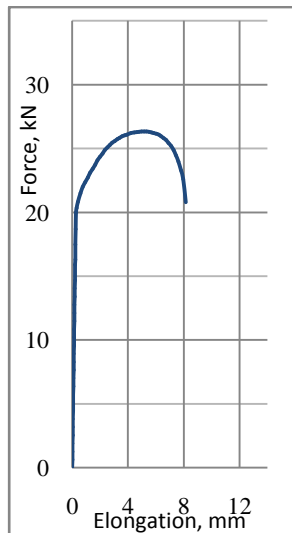
a) tested in the rolling direction



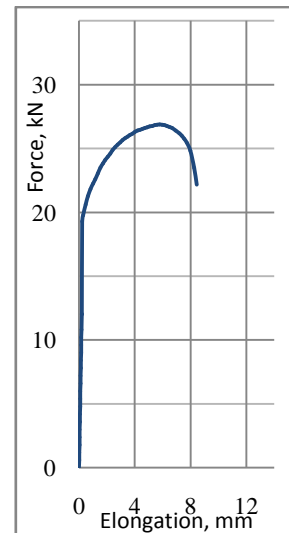
b) tested in the direction perpendicular to
the rolling direction

Figure 1. Force-elongation diagrams of Nb microalloyed steel

Figure 2 shows force-elongation diagrams of heated Nb microalloyed steel tested in the rolling direction (Figure 2a) and in the direction perpendicular to the rolling direction (Figure 2b). It can be seen also very similar curves for both test directions.



a) tested in the rolling direction



b) tested in the direction perpendicular to
the rolling direction

Figure 2. Force-elongation diagrams of heated Nb microalloyed steel



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Sisak, May 15th-17th, 2019

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When comparing Figures 1 and 2, it can be seen that by subsequent heating carried out at 1150 °C steel shows decrease of the yield stress values as well as oscillations of force values.

Results given in Table 2 were obtained from above diagrams (Figure 1). They show very similar data for Nb microalloyed steel in both tested directions. These values are high in comparison with values of conventional carbon steels [1].

Table 2. Mechanical properties of Nb microalloyed steel obtained by static tensile test

| Test direction / mechanical property | Yield stress, MPa | YS mean value, MPa | Tensile strength, MPa | TS mean value, MPa | Elongation, % | Mean value of elongation, % |
|---|-------------------|--------------------|-----------------------|--------------------|---------------|-----------------------------|
| in the rolling direction | 515 | 511 | 581 | 583 | 25.45 | 26.33 |
| | 508 | | 581 | | 27.32 | |
| | 509 | | 586 | | 26.22 | |
| in the direction perpendicular to the rolling direction | 518 | 524 | 583 | 588 | 26.35 | 25.96 |
| | 534 | | 595 | | 25.27 | |
| | 520 | | 585 | | 26.26 | |

As well as for the hot rolled but non-heated steel, values of mechanical properties of steel subsequently heated are very similar and relatively high (Table 3).

Table 3. Mechanical properties of heated Nb microalloyed steel obtained by static tensile test

| Test direction / mechanical property | Yield stress, MPa | YS mean value, MPa | Tensile strength, MPa | TS mean value, MPa | Elongation, % | Mean value of elongation, % |
|---|-------------------|--------------------|-----------------------|--------------------|---------------|-----------------------------|
| in the rolling direction | 401 | 404 | 508 | 508 | 19.01 | 17.96 |
| | 411 | | 507 | | 15.87 | |
| | 401 | | 508 | | 19.01 | |
| in the direction perpendicular to the rolling direction | 400 | 403 | 506 | 513 | 15.12 | 15.57 |
| | 404 | | 516 | | 15.80 | |
| | 404 | | 516 | | 15.80 | |

In comparison of values of mechanical properties for two types of studied steel (Table 2 and 3), it can be seen that subsequent heating resulted in decreasing of mechanical properties values. Further, heated steel has lost expressed yield point and there was no specific slowdown in the stress zone.

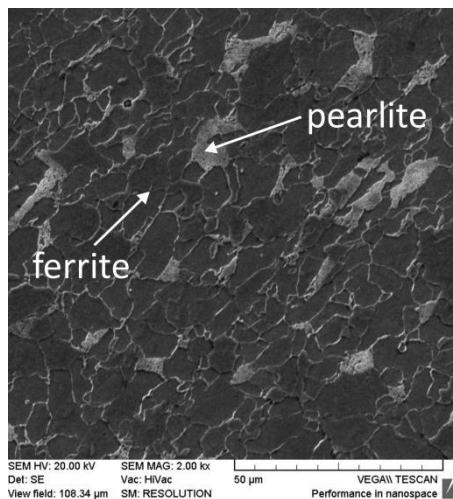


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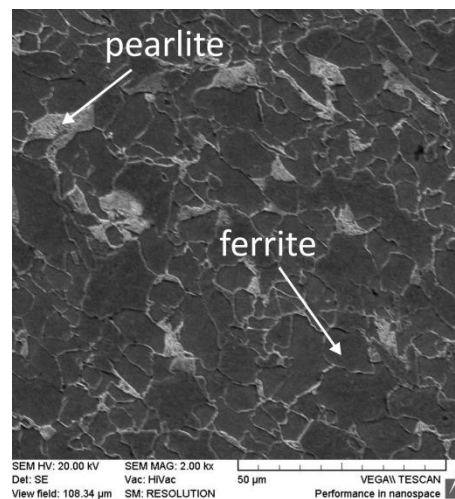
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The reason for such behavior could be found in the microstructures of studied steel. Namely, Figure 3 shows that microstructure of hot rolled steel microalloyed with 0.048 % niobium in both tested directions consist of polygonal ferrite, characterized by equiaxed and homogenous grains, and coarse lamellar pearlite. The banded ferrite pearlite structure has been commonly observed in hot rolled steels [8]. Formation of these microconstituents, primarily of polygonal ferrite could be attributed to the lowering of the niobium content in solid solution due to the strain-induced precipitation of niobium carbonitrides [9]. The consequence of similar microstructure in tested directions is a very similar mechanical properties showed above.



a) tested in the rolling direction



b) tested in the direction perpendicular to the rolling direction

Figure 3. SEM micrographs of Nb-microalloyed steel, 2000x

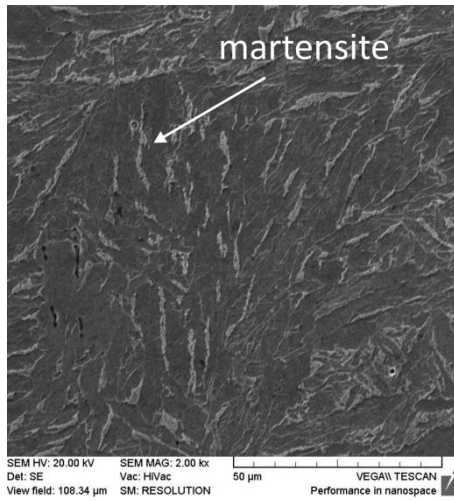
Figure 4 shows that microstructure of hot rolled steel Nb microalloyed subsequently heated at 1150 °C followed by air cooling in both tested directions is martensitic. Grains are coarser than in microstructure of hot rolled non-heated steel. This grain increasing could be attributed to the subsequent heating of hot rolled steel Nb microalloyed. Since there is no clear difference in microstructure observed in the rolling direction and in the direction perpendicular to the rolling direction, there is also negligible difference in mechanical properties values (Table 3).



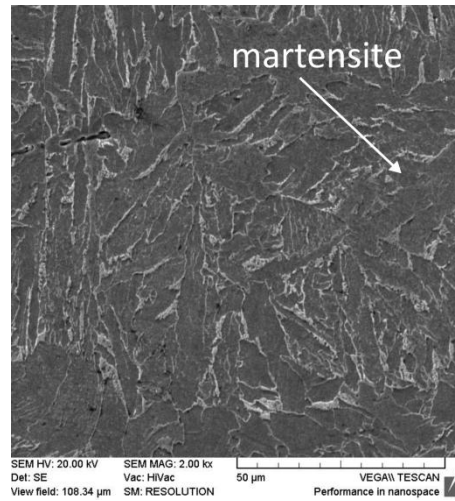
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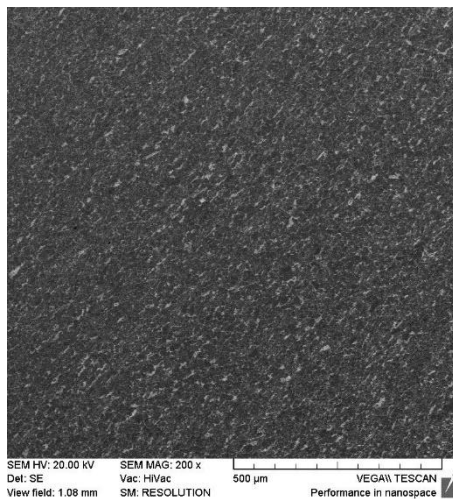
a) tested in the rolling direction



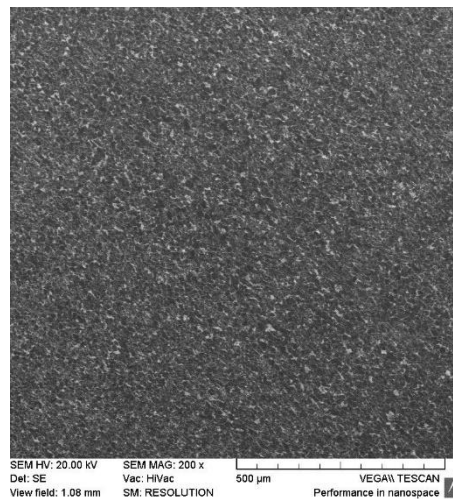
b) tested in the direction perpendicular to the rolling direction

Figure 4. SEM micrographs of heated Nb-microalloyed steel, 2000x

But microstructural comparison of two types of studied steel shows that above stated loss of emphasize yield stress could be attributed to the increase of grain size after subsequent heating that may be seen in Figs. 5 and 6.



a) tested in the rolling direction



b) tested in the direction perpendicular to the rolling direction

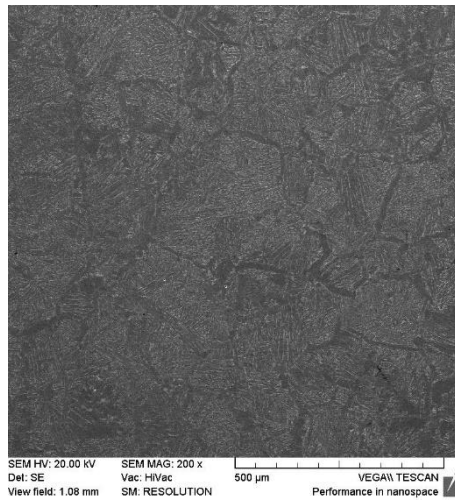
Figure 5. SEM micrographs of Nb-microalloyed steel, 200x



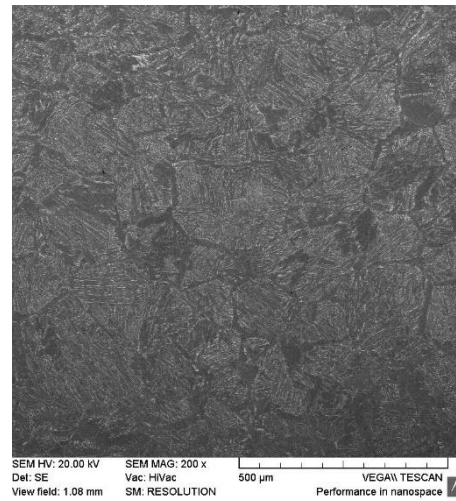
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a) tested in the rolling direction



b) tested in the direction perpendicular
to the rolling direction

Figure 6. SEM micrographs of heated Nb-microalloyed steel, 200x

Microconstituents that are evident in Figure 5 are ferrite and pearlite, while in Figure 6 is martensite visible. That means that again there is no significant difference against the testing direction regarding the microstructure.

CONCLUSIONS

Based on the obtained results it can be concluded as follows:

- Microstructure of hot rolled Nb microalloyed steel is ferritic-pearlit. Microstructure of this steel after heating at 1150 °C followed by cooling in the air is martensitic.
- Microstructure and therefore mechanical properties does not depend on the rolling direction.
- Subsequent heating of Nb microalloyed steel revealed the coarsening of grains and consequently loss of mechanical properties.

Acknowledgements

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