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Research Article

An Investigation of the Formability, Mechanical Properties and Microstructure of Niobium and Niobium-Titanium Microalloyed Steels

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Abstract:

Microalloyed steels are widely used in the automotive sector due to their formability and strength. One example application is rim manufacturing where the cost of wheel is expected to be low. In this study, formability, microstructure and mechanical properties of low carbon steels containing Niobium and Niobium-Titanium as microalloying elements were investigated. The measurements showed that the tensile strength of non-alloyed steel was 433.5 MPa, the yield strength was 292.6 MPa, the tensile strength of Nb alloyed steel was 489 MPa and the yield strength was 385.4 MPa. These values indicate that the tensile strength increase of about 12 % and the yield strength increase of 24 % were obtained. Also for Nb-Ti added steel, the tensile strength was 591.3 MPa and the yield strength was 462.6 MPa. These correspond to 27 % increase in the tensile strength and 37 % increase in the yield strength. Furthermore, elongation values were measured as 27.6 % in non-alloyed steel, 32 % in Nb-added steel, and 28 % in Nb-Ti added steel. In the microstructure analysis, the grain size of Nb and Nb-Ti added alloys were found to be approximately 50 % smaller than the grain size of unalloyed steel. These results indicated that we achieved high elongation values and improved mechanical properties for Nb and Nb-Ti added steel. Furthermore, we managed to hold the elongation value at 27.7 % while achieving higher yield and tensile strengths and formability by adding a small amount of Nb-Ti to the steel.

1. Introduction

Microalloyed or High Strength Low Alloy (HSLA) steels have been used since 1960s. They are estimated to be 12 % of total world steel production. The use of microalloyed steels has played an important role in the expansion of certain key industries such as oil and gas extraction, construction, and transportation [1].

In automotive sector, microalloyed steels enable the production of fuel efficient and improved performance vehicles. Many manufacturers in the automotive industries, have focused on the microalloyed steels because of their mechanical properties [2]. Microalloyed steels have small amounts of elements Nb, V and Ti whose contents vary from 0.001 to 0.1 %. These are combined with elements present in the steel (Mn, Si, Mo) to improve mechanical properties such as strength, toughness, ductility and weldability by the formations and precipitation of carbide, nitride and carbonitrides [3-6].

Mild steel has a lower yield strength, σy, of 150-200 MPa. On the other hand, microalloyed steels are designed to have a yield strength between 500 and 750 MPa without heat treatment, with the potential to exceed 1000 MPa [7]. The weldability of microalloyed steel is at least equal to that of mild steel, and can be improved by reducing carbon content while maintaining strength. In microalloyed steels, fatigue life and wear resistance are superior to similar heat-treated steels. The disadvantages are that ductility and toughness are not as good as quenched and tempered (Q&T) steels [8]. Furthermore, microalloyed steels permit reductions in component weight and manufacturing cost.

This work has investigated effects of Niobium and Niobium-Titanium additions in mild steels by examining microstructure and mechanical properties. The impact on the formability properties has also been examined.

2. Materials and Method

Samples used in this work were produced in an iron and steel plant located in Turkey. Fe-Ti ve Fe-Nb were used in the microalloying process. The Nb and Nb–Ti containing steels described here were applied industrial heating, continuous casting and hot rolled before sampling. The samples were subject to tensile tests. Optical and scanning electron microscope analyses were implemented for grain size measurements and fracture surface investigations. Table 1 shows non-microalloyed EN 10025-2:2004 S275JRC (RSt37-2), Nb-added EN 10149-2:2013 S355MC (QStE 380TM) and Nb-Ti added EN 10028-3 - P355NH (WStE 355) steels that were used in this work together with their chemical compositions.

Table 1. *Chemical composition of steels used in experimental study*

Alloying Element (%)	**EN 10025-2:2004 S275JRC (RSt37-2)**	**EN 10149-2:2013 S355MC (QStE 380TM)**	**EN 10028-3 - P355NH (WStE 355)**
C	0.14	0.08	0.17
Mn	1.2	0.9	1.6
Si	0.1	0.006	0.4
Ti	0.0003	0.0002	**0.017**
V	0.0005	0.0007	-
Ni	0.0326	0.028	0.0332
Nb	0.0001	**0.055**	**0.04**

Samples shown above in Table 1 were grinded and polished. This was followed by etching with 2% Nital solution for metalographic examination which was performed with Nikon Eclipse MA200 optical microscope. The grain size was estimated using a linear-intercept method. Intercept lengths were determined and then converted into nominal grain diameters using standard tables.
Standard tensile tests were conducted at room temperature on longitudinal specimens machined according to EN 6892-1 (ISO 6892-1:2016) specification [9] using computerised tensile testing system with Zwick / Z1200 equipment.

Fracture surface analysis were undertaken with JEOL JSM 5600 SEM (Scanning Electron Microscopy) to examine microstructure, distribution and morphologies of carbide and carbonitride compounds of microalloyed elements.

3. Results and Discussions

Figures 1-3 show microstructures of non-microalloyed EN 10025-2:2004 S275JRC (RSt37-2), Nb-added EN 10149-2:2013 S355MC (QStE 380TM) and Nb-Ti added EN 10028-3 - P355NH (WStE 355) steels, respectively.

In Figure 1, black areas show pearlite phase and white areas indicate acicular ferrite phase. Acicular ferrite is a structure that forms in unalloyed and low alloy steel during the solidification from the austenite phase. As can be seen, the amount of pearlite formation is limited. The average grain size was measured to be 7 μm.

In Figure 2, black areas show pearlite, white areas show ferrite and grey areas show Nb[C, N] carbides and nitrides. As can be seen, the grain size of microalloyed steel is smaller than that of the non-microalloyed steel. This is due to the precipitation of carbide and nitride at the grain boundry. The average grain size was measured to be 4 μm.

In Figure 3, black areas show pearlite phase and white areas show ferrite phase. The banded region shown in Figure 3a indicates the presence of Ti carbides. The grey areas show Nb carbides. The average grain size is measured to be approximately 5 μm. Furthermore, microstructures of added microalloying elements show that the amount of pearlite phase has increased. This may indicate that microalloying elements prevent ferrite formation while supporting pearlite formation.
For the tensile test, five samples were taken from each specimen group. The arithmetic means of measured values are shown in Table 2.

The results shown in Table 2 suggest that the yield strength of Nb-added steel has increased by 24 % compared to that of non-microalloyed steel. Similarly, the Nb-Ti added steel has its yield strength incerased by 37 %. The tensile strength was increased by 12 % for the Nb-added steel and 27 % for the Nb-Ti added steel compared to that of non-microalloyed steel. Preciptation phases affect mechanical properties of microalloyed steels. Microalloying elements, such as Nb and Ti and their combination, result in carbide, nitride and corbonitride precipitation phases.

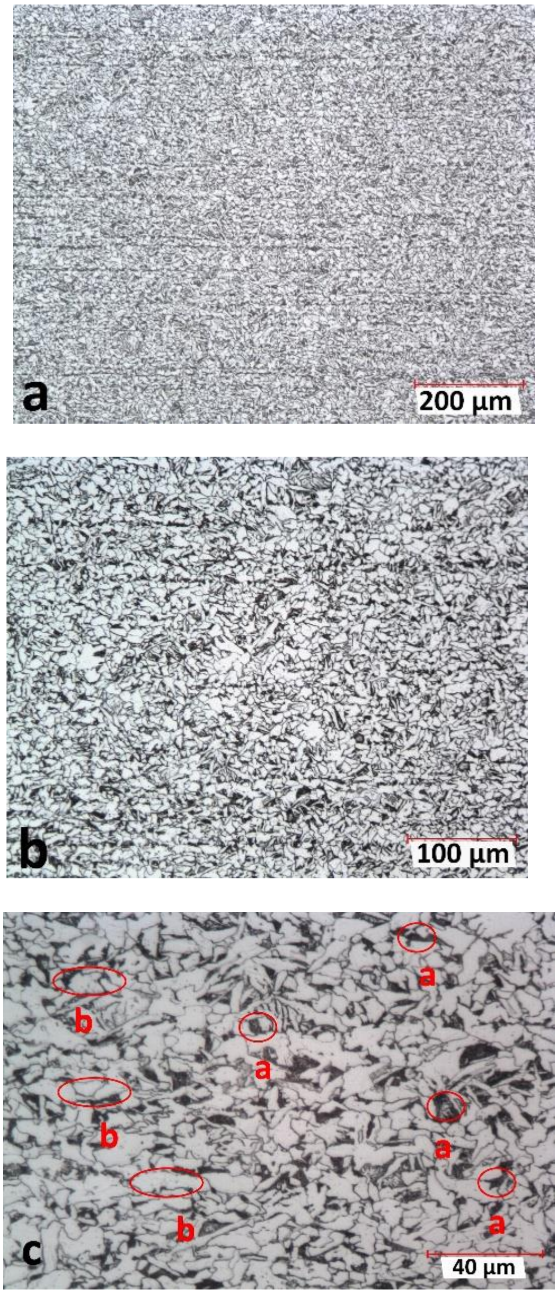
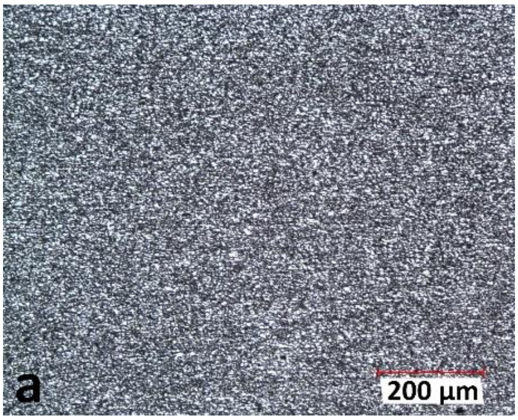


Figure 1. *Microstructure of non-microalloyed steel (EN 10025-2:2004 S275JRC (RSt37-2))*
(in figure c a : acicular ferrite b : pearite)



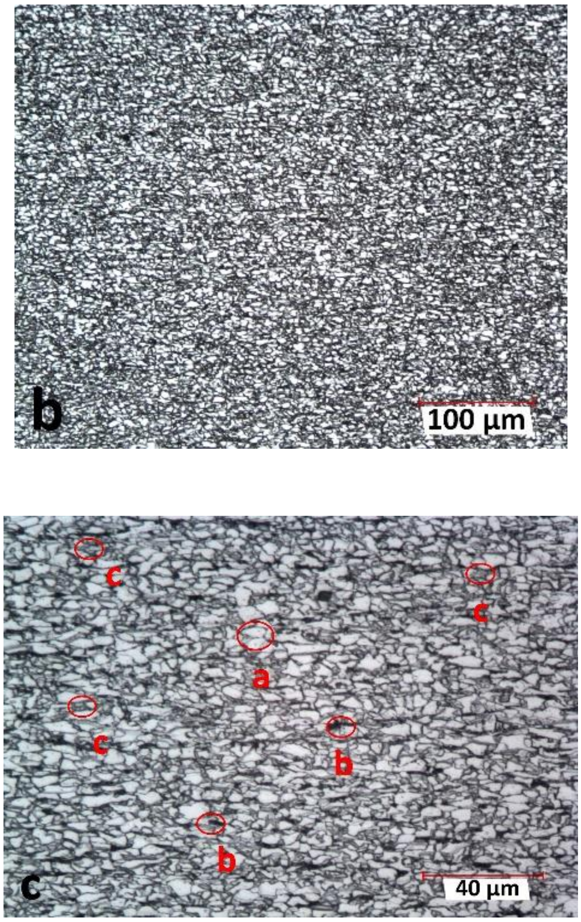


Figure 2. *Microstructure of Nb-added microallyed steel (EN 10149-2:2013 S355MC (QStE 380TM))*
(in figure c a : ferrite b : pearite c : NbC)

Table 2. *Tensile tests results.*

	EN 10025-2:2004 S275JRC (RSt37-2)	**EN10149-2:2013 S355MC (QStE 380TM)**	**EN 10028-3 - P355NH (WStE 355)**
Yield Strength (MPa)	292.6 ±3.45	385.4 ±13.74	462.6 ± 2.41
UTS (MPa)	433.5 ±7.95	489 ±8	591.3 ± 6.5
Elongation %	27.6	32	27.7

The distribution of these phases in microstructures prevents the dislocation movements and increases strength due to precipitation hardening [10]. Najafi et al [11] examined the impact of Nb and V in mechanical properties of microalloyed steels. They pointed out that the improvement in mechanical properties is the result of Nb(C,N) formation in ferrite phases. Our results are in agreement.

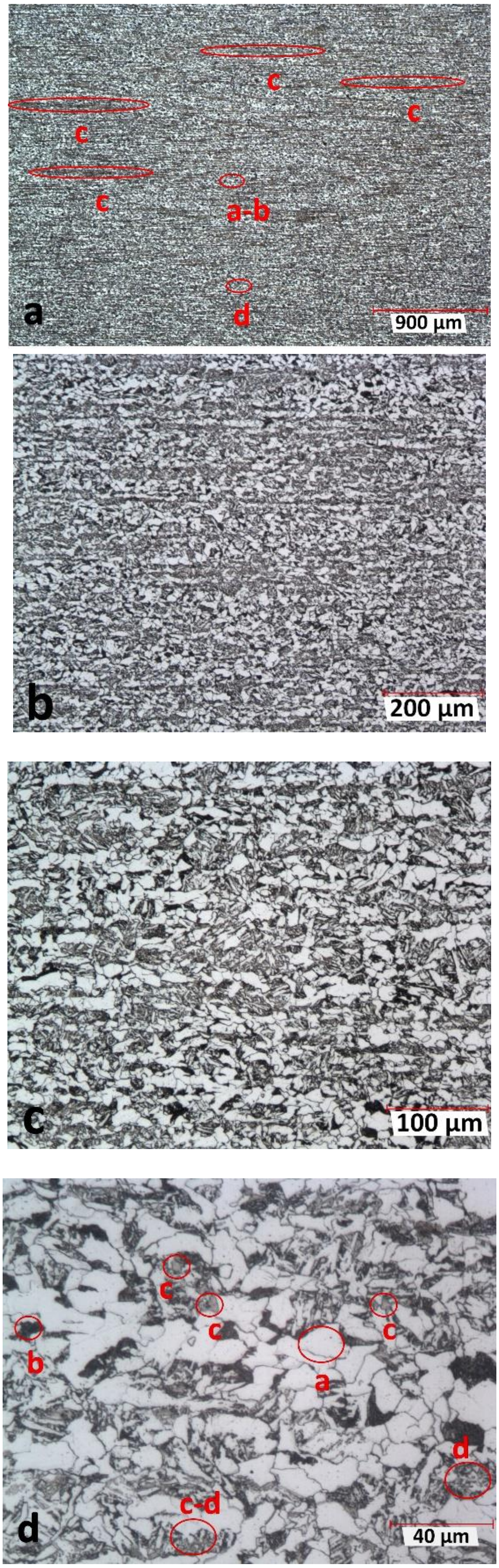


Figure 3. *Microstructure of Nb-Ti added microallyed steel **(**EN 10028-3 - P355NH (WStE 355))*
(in figure a,d a : ferrite b : pearite c : Ti[C,N] d : NbC)

El-Faramawy et al argued that the addition of Ti in steel for microalloying reduces the grain size and this prevents the dislocation movement which, in turn, causes improvement in the mechanical properties [12].

Fractography of tensile specimens was carried out under scanning electron microscopy and the fracture surfaces were examined. Nb and Nb-Ti added specimen were examined using SEM analyses (Figure 4). In Figures 4a and 4b, fracture surfaces of the Nb-added steel are shown. Figures 4c and 4d illustrate fracture surfaces of the Nb-Ti added steel. From these figures, we can observe better toughness depending on whether they show dimple ductile or cleavage fracture. If a specimen shows dimple and toughness features this can be an advantage in terms of formability. SEM photographs show that the Nb-Ti added specimen has sponge-like and matt fracture surfaces. The Nb-added specimen has more dense cleavage fracture than that of the Nb-Ti added specimen. In particular, we observe typical cleavage fractures. The Nb-Ti added specimen shows clear dimple ductile fractures. This suggests a presence of high energy and toughness. The cleavage fracture requires a low energy and it is intergranular. The result is a leaf-like shape. Fractures in the Nb-Ti added specimen are the result of fracturing at the grain boundry rather than fracturing inside the grains. Therefore, the Nb-Ti added specimen has resulted in higher toughness. Davis et al [13] examined the fracture behaviour of medium carbon Ti-V-N and V-N microalloyed ferritic-pearlitic ve bainitic steels. They suggested that Titanium reduces the austenite grain size, creates rough (Ti, V) (C,N) particules and decreases toughness by heat transfer. In our work, Vanadium was not used and, contrary to Davis et al, it was shown that Nb-Ti addition improves the toughness.

4. Conclusions

In this work, the formability and mechanical properties of Nb and Nb-Ti microalloyed steels were examined by comparing against mild steel. In order to examine the impact of Nb and Nb-Ti, EN 10149-2:2013 S355MC and EN 10028-3 - P355NH were selected, respectively. For non-microalloyed steel, EN 10025-2:2004 S275JRC was used. The results of tensile tests have shown that the yield strengths of Nb and Nb-Ti added steels were increased by 24 % and 37 %, respectively, compared to that of non-alloyed steel. Similarly, the tensile strengths of Nb and Nb-Ti added steels were increased by 12 % and 27 %, respectively, compared to that of non-alloyed steel.

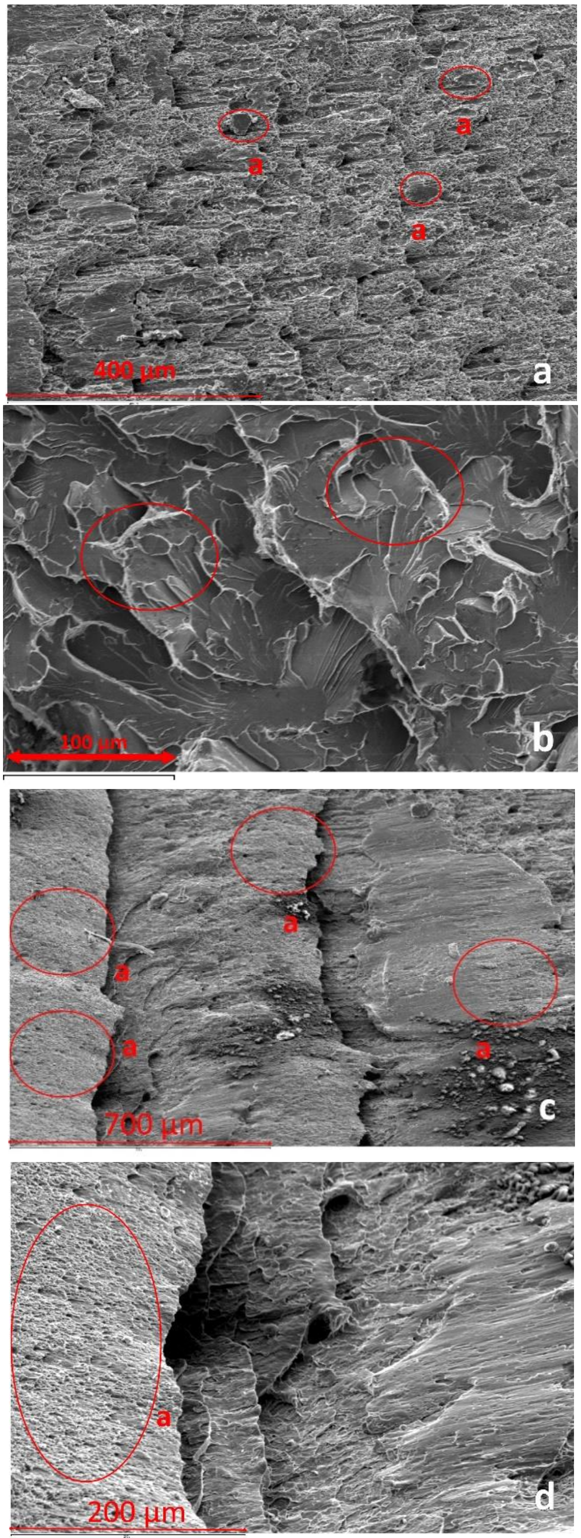


Figure 4. *Fracture surfaces of samples (a, b Nb-added steel, c and d Nb-Ti added steel)*
(in figure c and d,   a : dimple ductile fracture)

The average grain sizes of Nb and Nb-Ti added steels were measured as 4 and 5 µm, respectively. The grain size of the non-alloyed steel was 7 µm. The reduction in the measured grain size indicates better toughness which, in turn, leads to increasing yield and tensile strengths. These values also suggest that Nb and Nb-Ti added steels improve formability.

It should be noted that higher yield and tensile strengths and formability were achieved without reducing the elongation value by adding a small amount of Nb-Ti to the steel.

It was also shown that microalloying elements prevent ferrite formation and support pearlite formation.

When comparing the formability properties of Nb and Nb-Ti added steels the fracture behaviour relating to ductile and toughness features was considered. It was shown that Nb and Nb-Ti added steels have a better formability properties compared against the formability properties of non-alloyed steels.

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