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EFFECT OF SEVERE HOT DEFORMATION AND DIFFERENT COOLING RATES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 0.2 C-0.1 V- 0.02 Nb STEEL

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ABSTRACT

Rebar steels are usually processed from carbon steel. However, carbon limits the deformability and weldability of steel rebars. Microalloying with V and Nb is the optimum solution when high strength in combination with good formability and weldability are essential. Nb replaces V partially for better ductility purposes. Nb plays a bilateral role where, it forms carbonitride which acts as precipitation strengthener. Further active role is played by Nb in grain refinement which would improve appreciably the yield strength and ductility. However, to get full benefit of Nb micro-alloying, the soaking temperature, deformation amount, finish rolling temperature and cooling after rolling should be taken into consideration.

The present article is dealing with 0.2 % C, 0.1% V, and 0.02% Nb steel. Billets with 130×130 mm cross section are austenitised and hold at 1080^{o}C. The billets were hot rolled to 22 mm bar diameter. Hot rolling was finished at 980-1000^{o}C. The final bars were air cooled. On a parallel way, an experimental hot deformation investigation, on the same steel, was carried out at deformation temperature range 1200-850^{o}C with the same amount of deformation (97% reduction in area). However, cooling regimes after deformation were air cooling, water quenching to 850^{o}C followed by air cooling, and water quenching to room temperature. Microstructure investigation was done using both optical and scanning electron microscopes. Further evaluation was done using mechanical testing. The industrial trial has unsatisfied results with a poorer yield strength linked with higher ultimate strength due to islands of abnormal coarse grains of mixed hard phases surrounded by ferrite grains. Bainitic as well as martensitic aggregates are detected in the hard phases islands. Air cooling after pilot hot deformation creates banded ferrite–pearlite microstructure with 9.11μm ferrite grains. However, quick water quenching to 850^{o}C followed by air cooling develops tempered and softened martensite phase. One the other hand, quick water quenching to room temperature develops fine ferrite-martensite texture. Water quenching to 850^{o}C followed by air cooling is the best regime creating accepted mechanical properties.

KEYWORDS: Carbon Steel, Nb Steel, Microstructure Banding, Hot Deformation

INTRODUCTION

Heavy deformation has much attention due to strain induced phase transformation which is an effective tool for grain refinement [1–4]. However, ultra fine grains which are obtained by heavy deformation exhibits more grain coarsening than conventional fine grains, since the grain boundaries are in a non equilibrium high energy state, [5,6]. In order not to loose the advantage of fine grained microstructures during subsequent heat treatment, the microstructure stability should be maintained. Several previous investigations revealed that grain growth rate is reduced by microalloying elements such as Mo, Nb and V [7,8]. These substitutional alloying elements influence appreciably the γ/α interface motion through a solute drag-like effect. Nb, especially, affects the growth rate of ferrite considerably by solute drag of Nb as well as by pinning of the precipitates (carbo-nitrides), [9,10]. Abnormal grain growth can occur during annealing after deformation even in Nb steel as a result of greater driving force for abnormal grain growth than that responsible for inhibition of normal grain growth [11]. The strain induced boundary migration (SIBM) during annealing after deformation leads to bimodal distribution of grain size [12]. The SIBM occurs by the inhomogeneity of strain energy between the neighboring grains [11]. The present work investigates the abnormal grain growth behavior during isothermal holding after heavy deformation for Nb/V rebars steel.

EXPERIMENTAL WORK

An industrial trial of 75 ton of grade BST 500S has been processed with V/Nb microalloying. The steel has the following chemical composition as listed in Table 1;

Table 1: Chemical Compositions, wt%

C	Si	Mn	P	S	V	Nb	N(ppm)
0.20	0.17	1.33	0.015	0.009	0.106	0.020	40

In the industrial trial, the steel billets with 130×130 mm cross section are austenitised and hold at 1080°C. The billets were hot rolled on 14 stands roll mill to a final 22 mm bar diameter. Rolling was finished at 980-1000°C. The final bars were air cooled. On a parallel way, a pilot severe hot deformation investigation, on the same steel, was carried out at deformation temperature range 1200-850°C with the same total amount of deformation (97% reduction in area). However, cooling regimes after deformation were air cooling, water quenching from 850-600°C followed by air cooling, and water quenching from 850°C to room temperature as shown in Figure 1. The reduction per pass was approximately 45% in cross-sectional area. Microstructure investigation was carried out by optical and scanning electron microscopy. Further evaluation was done using mechanical testing.

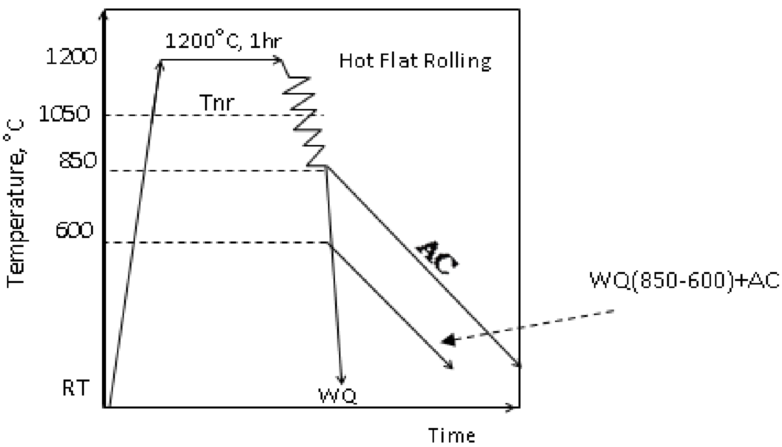

Figure 1: Schematic Diagram of Pilot Hot Deformation Processing

RESULTS AND DISCUSSIONS

The chemistry of the steel includes combined micro-alloying with V and Nb. Nb activity equation proposed by Irvene, [13]; can be applied on the present steel.

$$Log\left[Nb\%\right]\cdot\left[C\%+\frac{12}{14}N\%\right]=2.26-\frac{6770}{T}$$

Figure 2 represents the beneficial active Nb in the presence of different carbon contents with 40ppm N_2 and 1080°C heating temperature.

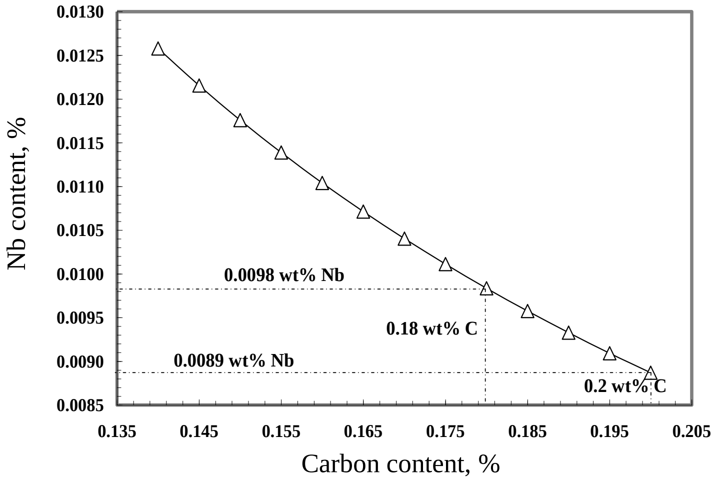

Figure 2: Active Nb in the Presence of Different Carbon Contents with 40ppm N_2 and 1080°C Heating Temperature

Depending on the amounts of N and C, it is clear that the active Nb should be 0.009% and the rest can be considered as excess addition in the heat of industry. However, to make more benefits of Nb, carbon could be decreased and austentizing temperature should be increased. Processing conditions highly affect the mechanical properties of rebars. Table 2 represents standard tensile properties of grade BST 500S (Target) compared with the actual measured properties.

Table 2: Standard (Target) Tensile Properties of Grade BST 500S Compared with the Actual Measured (Trial) Properties

Steel	Yield Strength, MPa	Ultimate Strength, MPa	Elongation, %
Target BST 500S	500	600	≥ 15
Industrial Trial	475	670	14

It is clear that the steel of the industrial trial has unsatisfied results with a poorer yield strength linked with higher ultimate strength. Such results are usually attributed to the formation bainite and/or martensite aggregates instead of pearlite-ferrite structure. Figure 3 shows the microstructure of the steel industrial trial. The micrograph reveals islands of mixed hard phases (Bainite) surrounded by coarse ferrite grains.

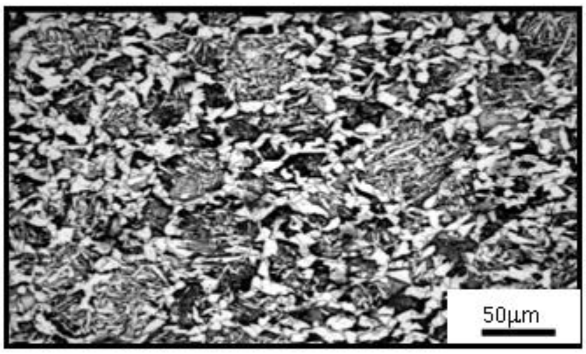

Figure 3: Microstructure for 22mm Steel Bar of Industrial Trial

SEM micrographs at high magnifications clarify and separating the aggregates of mixed phases. Figure 4 reveals the coarse ferrite grains surrounding the islands of mixed phases. It was demonstrated by Bhadeshia that the reason of such morphology (the coarse ferrite grains surrounding the islands of mixed phases) is due to non-metallic inclusions which is responsible for nucleation of acicular ferrite/bainite. The average ferrite grain size is 20μm. The size of mixed phases is ranging 20-40μm. Abnormal grain growth can occur during annealing after deformation even in Nb steel as a result of greater driving force for abnormal grain growth than that responsible for inhibition of normal grain growth by Nb [11], which is the case of the present industrial trial where the finishing temperature after deformation is high (980-1000^{o}C) and rate of cooling was low (air cooling).

Furthermore, coarse ferrite grains could be created by slow cooling of unconditioned austenite, where conditioned austenite needs high amount of deformation per pass at a temperature lower than the recrystallization stop temperature (T_{nr}=1050°C). Furthermore, deformation should be continued to very near α–γ transformation temperature (890-900°C), [14], which is not dominated at the present trial.

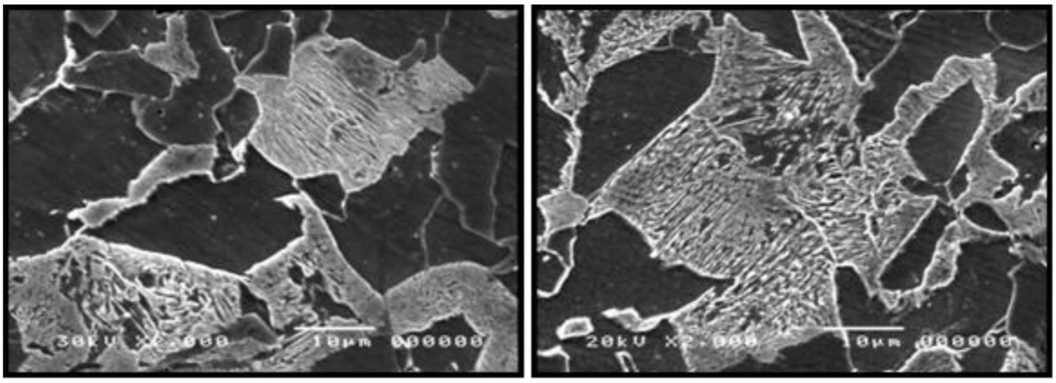

Figure 4: Ferrite Grains with 20um Grain Size Surrounding Aggregates of Mixed Hard Phases

Zooming out on the hard phases islands with higher magnifications, the micrograph in Figure 5 shows clearly one of the aggregates inside the mixed phases islands. However, in some other places inside hard phase islands, SEM micrographs detect bainite aggregates, Figure 6.

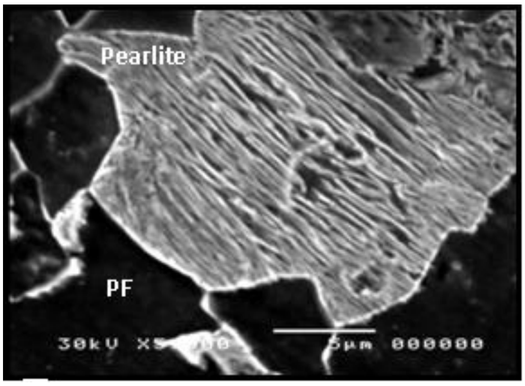

Figure 5: Pearlite inside the Mixture of Phases Islands

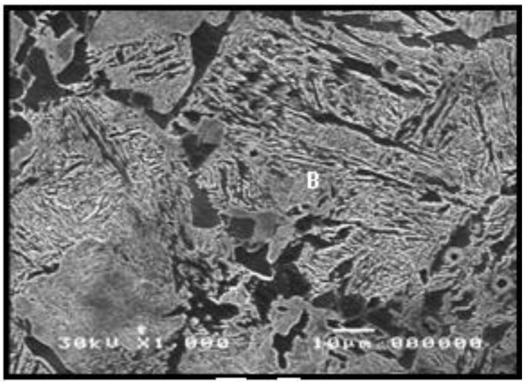

Figure 6: Bainite inside the Mixture of Phases Islands

On the other hand, pilot hot deformation, with different cooling rates, creates different microstructure accompanied with different mechanical properties. Deformation is continued in the temperature range 1200-800^{o}C. From dilatation investigation,γ/α transformation starting (720°C) and finishing temperature (540°C), [15], where ferrite transformation of Nb steel was delayed owing to the soluble Nb. Lee *et al.*[15] have suggested that solute Nb strongly segregates to γ/α interphase boundary and reduces ferrite growth kinetics due to solute drag effect. All previous information insure the pilot deformation have been performed at temperatures lower than the recrystallization stop temperature (T_{nr}) and finish near to the γ/α transformation temperature. Figure 7 shows the effect of air cooling after deformation on steel microstructure. It is banded ferrite-pearlite microstructure. Banding phenomena is created as a result of slow rate of cooling by air, [16]. Ferrite grains are sized 9.11μm. slow cooling by air adversely affects the effect of both Nb and deformation.

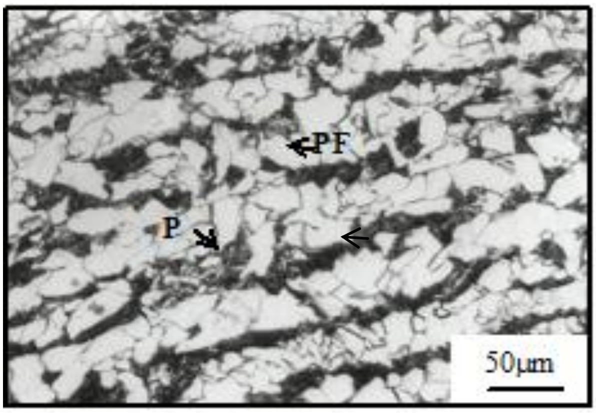

Figure 7: Ferrite – Pearlite Microstructure of Air Cooled Steel after Deformation, PF, Polygonal Ferrite; P, Pearlite

The second cooling regime, after deformation, is water quenching from 850 to 600°C followed by air cooling. Figure 8 represents the microstructure of the present regime. It creates bainite phase during the early stages of water quenching. However, the steel contains enough heat that can temper and soften the early formed bainite,[16], which would result in modifying the ductility of steel but lowering the strength.

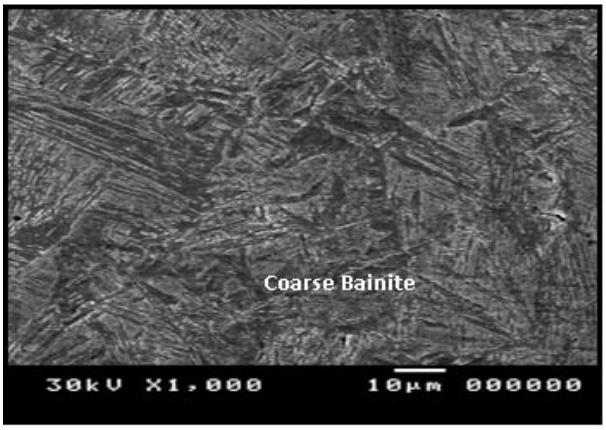

Figure 8: Water Quenching-Air Cooled Microstructure

Figure 9 represents the micrograph of steel subjected to quick water quenching to room temperature after deformation. The microstructure contains fine ferrite-bainite texture, as a result of high rate of cooling.

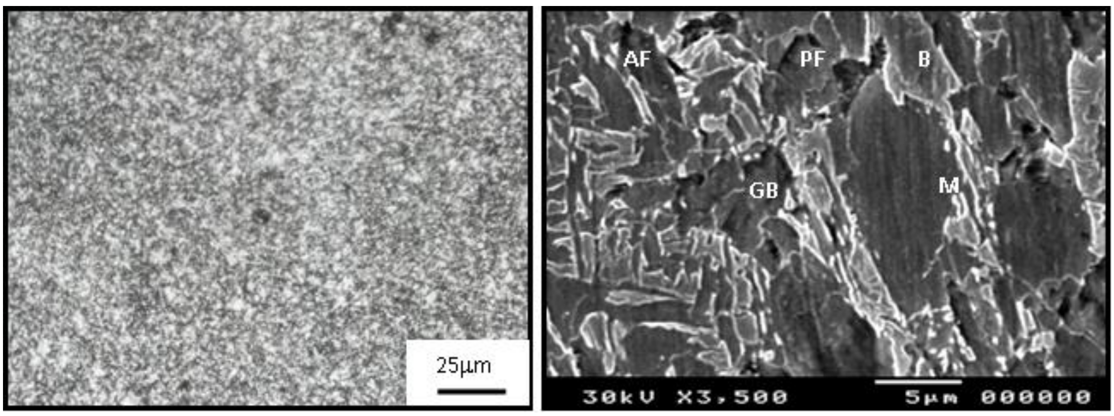

Figure 9: Water Quenched Microstructure, PF, Polygonal Ferrite; M, Martensite; AF, Acicular Ferrite; GB, Granular Bainite

The effect of different cooling regimes after deformation reflects on the mechanical properties of steel as it is clear in Figure 10. Water quenching followed by air cooling is the best regime after deformation, where it results in accepted values of ultimate as well as yield strengths. Furthermore, elongation is reasonable, which is not satisfied by the quick water quenching. Air cooling after deformation has also satisfactory results.

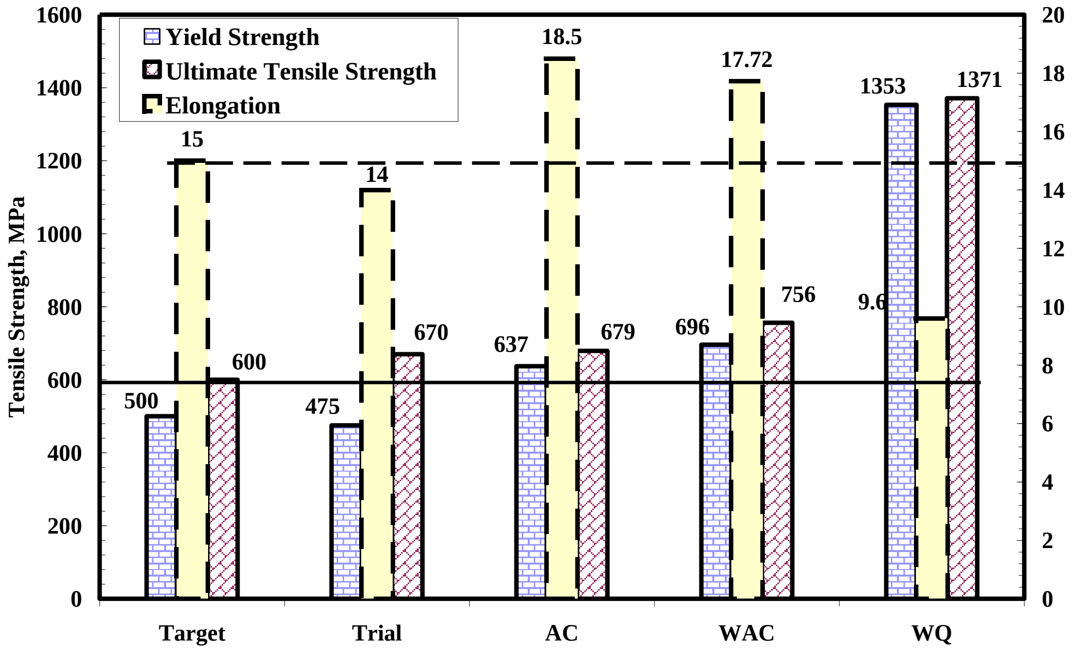

Figure 10: Tensile Properties of Steel at Different Conditions

CONCLUSIONS

- The industrial trial has unsatisfied results with a poorer yield strength linked with higher ultimate strength due to islands of mixed hard phases surrounded by coarse ferrite grains instead of pearlite-ferrite structure.
- Coarse ferrite grains (20μm) are created by slow cooling of unconditioned austenite and abnormal grain growth of mixed hard phases islands is achieved (20-40 μm).
- Bainitic as well as martensitic aggregates are detected in the islands.
- Air cooling after pilot hot deformation creates ferrite–banded pearlite microstructure with 9.11μm ferrite grains.
- Water quenching from 850°C followed by air cooling after deformation creates tempered and softened martensite phase.
- Water quenching from 850 to room temperature after deformation develops fine ferrite-martensite texture.
- Water quenching 850 to 600°C followed by air cooling is the best regime after deformation, where it results in accepted values of ultimate as well as yield strengths with reasonable elongation.

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