# AUSTENITE GRAIN SIZE CHANGE OF Nb-V STEEL IN DEPENDANCE ON CONTROLLED ROLLING CONDITIONS

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**Abstract**
The plastic deformations processing were realized on material known as high strength low alloyed (HSLA) steel microalloyed by niobium and vanadium. The samples were reheated on 1100°C to dissolution of microalloying element. The plastic deformation process was realized at 950, 1000 and 1050°C deformation temperature, which was the same as annealing temperature. The samples were deformed by 10, 20, 40, 50 and 60 % deformation and annealed for 0, 20, 40, 80 and 100 s. After the annealing the average austenite grains size were determined. At 1000 and 1050°C deformation temperature the fully static recrystallization was observed. At 950°C the samples deformed at 10 and 20 % deformation were fully recrystallized, but the samples at 40, 50 and 60 % shown elongated unrecrystallized grains. The elongated unrecrystallized austenite grains were determinated through effective nucleation area of grain boundary and deformation band. In general, the increasing deformation temperature has shown smaller grain size of austenite and with annealing time the negligible decrease of average AGS can be observed.

**Keywords:** plastic deformation controlled rolling, recrystallization, average austenite grain size (average AGS), Nb-V steel

## 1 Introduction

Thermomechanical control processing represent controlled rolling together with controlled cooling, where the reheating temperatures are lower than in the classical rolling process. Controlled rolling can be realized in three different temperature regions. The first region ($T_{deformation}$≥1000°C) represented by spontaneous recrystallization region of austenite, where the recrystallized austenite grains are created. If the deformation temperature decreases below 950°C temperature, this temperature is known as non-recrystallization temperature ($T_{NR}$), the plastic deformations are realized in delayed recrystallization region of austenite. Delaying of recrystallization is caused by presence of microalloying precipitates (carbides, nitrides and/or carbonitrides). During the rolling process in this region, the elongated austenite grains in rolling direction are created and observed. At the determinated degree of plastic deformation the formation of deformation bands is observed too. If the elongated austenite grains go into phase transformation, the ferrite can nucleate on austenite grain boundaries and deformation bands.

The last region of controlled rolling is finishing of rolling process in (γ+α) phase region, where the temperature is below $T_{def} \leq 850°C$. Plastic deformations create elongated austenite grains and the ferrite grains are deformed too. During the following cooling the unrecrystallized austenite transforms into equiaxed ferrite grains and deformated ferrite creates fine grains [1-13].
The magnitude of the effect of deformation is of course strongly dependent on the deformation conditions (strain rate, strain and temperature) via their effect on the nature and scale of the substructure and the dislocation density [14].
The rolling temperature affects both the rate at which recrystallization occurs and the rate of austenite grain growth after recrystallization. Consequently, a smaller austenite grain size is likely to be developed after rolling at the lower temperatures, which results in a finer ferrite grain size [15].
The subject of present work is to determine the average austenite grain size (average AGS) after the plastic deformation.

## 2 Experimental procedure

The experimental procedure was realized according to schedule in **Fig.1**. on steel with chemical composition described in **Tab.1**.
The specimens with dimensions 25 x 30 x 50 mm were used to experimental processing.
The reheating temperature 1100°C was selected with respect to dissolution of microalloying elements. After the reheating the samples were deformed at given deformation temperature (from 950 to 1050°C with ΔT= 50°C) by given deformations (ε= 10, 20, 40, 50 and 60 %) and annealed for ($t_{annealing}$=0, 20, 40, 80 and 100 s) at given deformation temperatures immediately followed by samples quenching. The strain rate used in rolling processing was 5 $s^{-1}$.
Metallographic samples were cut out from rolled samples for measurement of average AGS. To highlight the structure for light optical the etching in a saturated solution of picric acid was used.

**Table 1** Chemical composition of investigated material (wt.%)

| C | Mn | Si | P | S | V | Nb | Ti | Al | B | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.12 | 1.54 | 0.12 | 0.004 | 0.001 | 0.18 | 0.048 | 0.010 | 0.015 | 0.0005 | 0.0042 | 0.0015 |

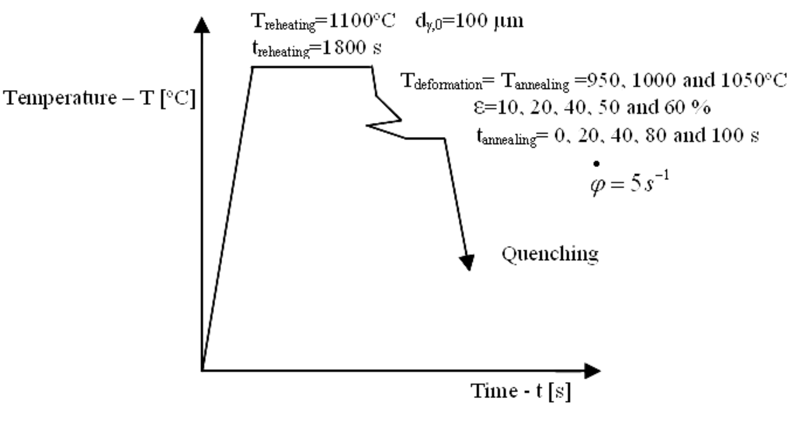


**Fig.1** Experimental schedule of C-Mn-Nb-V steel controlled rolling

The starting grain size before plastic deformation processing was 100 μm.

**Determination of average AGS at 950°C deformation temperature**

The average AGS of samples with 10 and 20 % deformation were calculated by the same way as samples at 1000 and 1050°C deformation regimes.

The average AGS at 40, 50 and 60 % deformation was determined by the equations used in [16]. These authors present that the grain size can be calculated through effective nucleation area $S_v$ ($mm^{-1}$) characterizing the equivalent area ($mm^2$) of the unit of volume ($mm^3$). The total effective nucleation area can be expressed by authors [16] as the sum of the effective nucleation area of the boundaries of austenite grains $S_v(gb)$ and of deformation bands $S_v(db)$.

$$S_v(gb+db) = S_v(db) + S(gb) \tag{1}$$

$$S_v(db) = 157.2\ x\ \varepsilon - 59.47 \tag{2}$$

$$S_v(gb) = 1000\ x\ [(0.429\ x\ d_{\gamma,//}) + (1.571\ x\ d_{\gamma\perp})] \tag{3}$$

$$d_{\gamma,korig} = \frac{2000}{S_v(db+gb)} \tag{4}$$

Where:

$S_v$ (db) [$mm^{-1}$] is the area of the deformation bands inside the austenite grains

$S_v$ (gb) [$mm^{-1}$] is the effective nucleation area of the grain boundaries

$d_{\gamma//}$ [μm] is the diameter of recrystallized austenite grains before deformation in nonrecrystallized region of austenite measured in parallel direction with rolling direction

$d_{\gamma\perp}$ [μm] is the diameter of recrystallized austenite grains before deformation in nonrecrystallized region of austenite measured in vertically direction with rolling direction

$d_{\gamma,korig}$ [mm] is the corrected average diameter of an austenite grain

## 3 Results and discussion

**Effect of plastic deformation on the average AGS**

**Effect of plastic deformation on the average AGS change at 1050 and 1000°C deformation temperature**

For investigated annealing temperature 950, 1000 and 1050°C only 1000 and 1050 °C show the very similar dependence as is shown in **Fig.2**. It is very important to highlight that this temperature ensure fully static recrystallization in spontaneous recrystallization region of austenite. The 950°C is the temperature, where the delayed recrystallization of austenite can be observed.

The biggest change of average AGS is observed for 10 and 20% deformation, which is related to intercritical deformation of austenite influencing the formation of unequal structure. At 1000 and 1050°C temperature and 10 and 20 % deformation the change of average AGS is in 10 – 15 μm range.

At 10 and 20 % deformation and 1050°C annealing temperature the average AGS is practically identical. The biggest change of average AGS is observed at 20 to 40 % deformation, where each 10 % deformation causes 3.8 μm decreases of average AGS. In 40 to 60 % deformation range the each 10 % deformation causes 1.55μm decrease of average AGS.

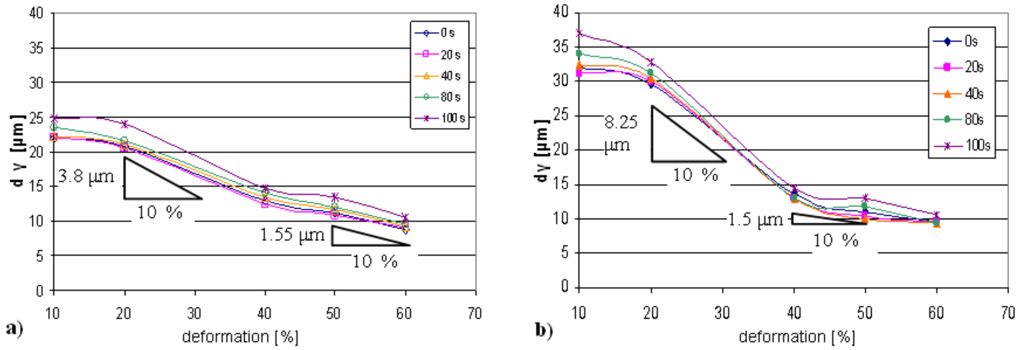


**Fig.2** Dependance of average AGS change on plastic deformation at annealing temperature: a) 1050°C b) 1000°C

After 10, 20 % deformation and annealing at 1000°C the average AGS is approximately about 15μm higher than at 1050°C and it has a similar behaviour. At 20 to 40 % deformation range the each 10 % deformation causes approximately about 8.25μm smaller grain. At 40 to 60 % deformation is observed only minimum 1.5μm change of grain size.

## Effect of plastic deformation on the average AGS change at 950°C deformation temperature

At this temperature two regions can be described as is shown in **Fig.3**. The first region (recrystallization region of austenite) which consists of 10 and 20 % deformation shows only a little influence of AGS change with comparison of origin AGS. The second region (nonrecrystallization region of austenite) consists of 40, 50 and 60 % deformation shows that above 40 % deformation the formation of deformation bands inside origin austenite grains is observed and it is in good coincidence with experimental results from [7] research work. After this and higher ($\varepsilon \geq 40$, 50 and 60 %) deformation the elongated deformed austenite grains with deformation bands can be observed. In this region (nonrecrystallization region of austenite) the $d_{\gamma,korig}$ are considered and the determination of average AGS were realized using Eq.1-4. The deformed austenite and new nuclei of austenite are visible only at 60 % deformation and 100 s annealing time.

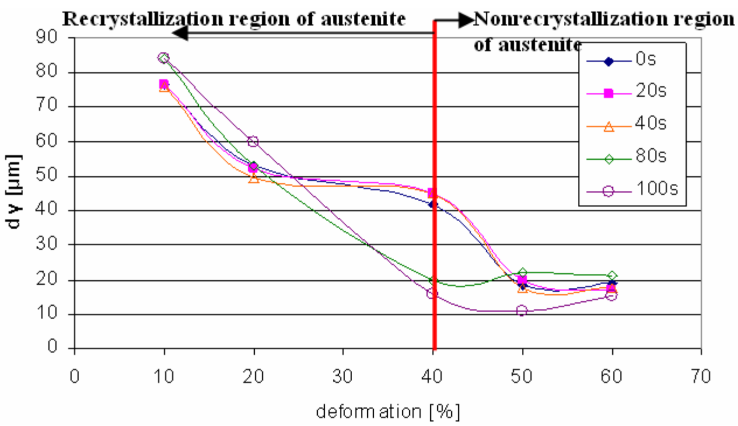


**Fig.3** Dependance of average AGS change on plastic deformation at 950°C annealing temperature

**Effect of annealing time on the average AGS change**

**Effect of annealing time on the average AGS change at 1050 and 1000°C deformation temperature**

Practically identical trend of the average AGS with annealing time can be observed in comparison with 1000 and 1050°C as is shown in **Fig.4**.

With increased annealing time only negligible growth of average AGS is observed.

In both figures are shown the two regions which are mutually shifted of about 7-10μm. Both figures represent a fully statically recrystallized austenite. From this observation can be said, that increased annealing time has slight influence on AGS changing.

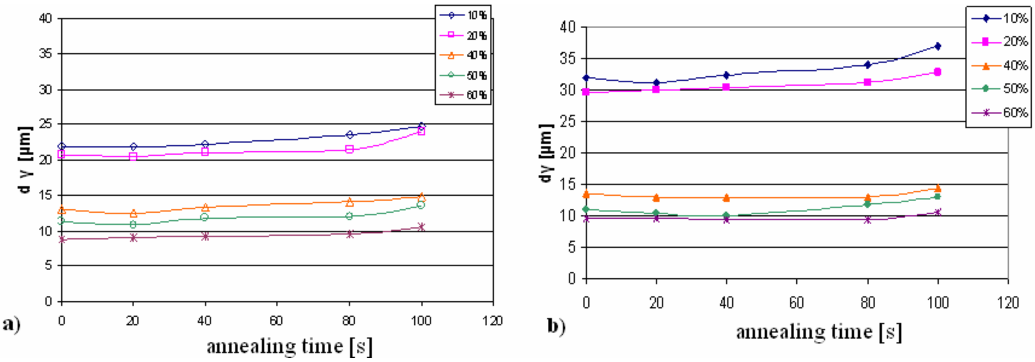


**Fig.4** Dependace of average AGS change on annealing time a) 1050°C b) 1000°C

**Effect of annealing time on the average AGS change at 950°C deformation temperature**

The recrystallized and unrecrystallized austenite grains are observed at this temperature as it is shown in **Fig.5**.

The fully recrystallized grains are observed at 10 and 20% deformation and all of given annealing times. These deformations show a similar trend as at 1000 and 1050 °C deformation temperature, but the average AGS is approximately about 60μm higher.

The unrecrystallized elongated grains are observed at 40, 50 and 60 % deformation. The 40 % deformation and 0, 20 and 40 s of annealing time represent start of deformation bands creation through the biggest decreases of grain size. At 50 and 60 % deformation only elongated austenite grains were observed. The average AGS were determinated using **Eq.1-4**.

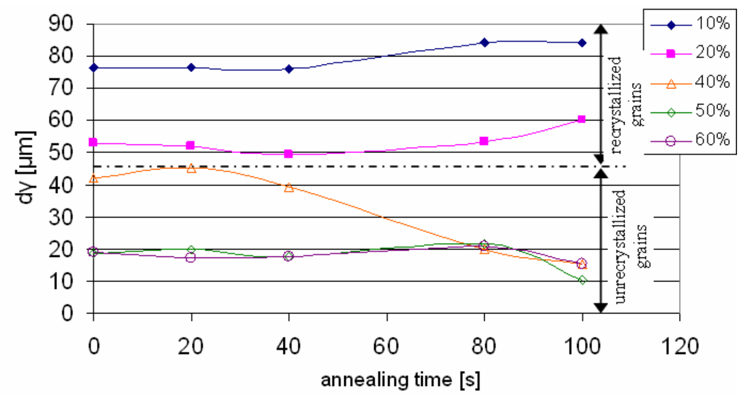


**Fig.5** Dependace of average AGS change on annealing time at 950°C annealing temperature

## 4 Conclusions

From these results we can conclude that:

- dominant influence on average AGS is caused by plastic deformation
- minimal effect on average AGS is caused by annealing time
- applied deformations and annealing temperatures 1000 and 1050°C ensure a fully static recrystallization of austenite
- at annealing temperature 1050°C two regions of average AGS change are observed, where the first group is in 23 ± 2μm range and the second group is in 13 ± 2 μm range
- at annealing temperature 1000°C two groups of average AGS change are observed, where the first group is in 34 ± 4 μm range and second region is in the the same range as it is at 1050°C (13 ± 2 μm)
- at annealing temperature 950°C the biggest AGS are observed in comparison with 1050 and 1000°C temperature, this temperature is known as non-recrystallization temperature, where the elongated unrecrystallized grains are observed
- at the 950°C annealing temperature is observed:
  a) the average AGS is in the 66 ± 16 μm range in first region, where ε = 10 and 20 % deformation created typically recrystallized grains
  b) the average AGS is in 28 ± 18 μm range in the second region where ε= 40, 50 and 60 % deformation created unrecrystallized elongated grains determinated using Eq.1-4 with deformation bands inside origin austenite grains

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