Journal of University of Science and Technology Beijing
Vol.8(2001), No.3, p.218

Materials

Comparison of Ferrite Refinement Mechanisms by Different Processing Schedules in 08 and 20Mn Steels

Ping Yang, Feng'e Cui, Shicai Ma

Material Science and Engineering School, University of Science and Technology Beijing, Beijing 100083, China
(Received 2000-10-12)

Abstract: The influence of deforming temperature on ferrite refinement was analyzed by comparing the microstructures obtained by deformation at above A_{r3}, in two-phase region of ($\alpha+\gamma$) and at below A_1 in clean 08 and 20Mn steels. The results indicate that ferrite refinement through strain induced transformation by deformation at above A_{r3} is more effective than that by deformation simply through ferrite dynamic recrystallization. The main problem of ferrite refinement by deformation at below A_{r3} is the inhomogeneity of microstructure which is controlled by the orientations and sizes of ferrite grains and the distribution of second phases. Ferrite dynamic recrystallization after strain induced transformation can further effectively refine ferrite.

Key words: clean carbon steel; strain induced transformation; grain refinement; ferrite dynamic recrystallization

[*The work was financially suported by the University of Scoence and Technology Beijing on the project 'Supersteel'.*]

1 Introduction

In contrast to the microalloyed steels which can be strengthened by phase transformation, precipitation, solution strengthening and grain refinement, no particular strengthening mechanism except grain refinement can be applied to enhance the strength of hot rolled low plain carbon steels. It is known that both strain induced transformation proposed as early as 1980's in Japan [1, 2] and ferrite dynamic recrystallization [3] can be utilized to refine ferrite, therefore various thermal-mechanical processing schedules such as the deformation at above A_{r3}, in two-phase region of ($\alpha+\gamma$) and at below A_1 were developed for the ferrite refinement. The main idea of strain induced transformation is to strongly undercool austenite and heavily strain it at near A_{r3} to obtain ultra-fine ferrite grains. The deformation in two-phase region is mainly conducted in consideration of the low deformation resistance of steels against rolling machines. It was reported [3] that heavy strains of over 5 is needed in order to acquire ultra-fine ferrite grains in IF steels. This work aims to compare the effectiveness in ferrite refinement through changing deformation temperature in 08 and 20Mn steels.

2 Experimental

The materials used are clean 08 and 20Mn steels with their compositions listed in **table 1**.

Table 1 Chemical compositions of used materials %

Materials	Chemical composition (mass fraction)						
	C	Si	Mn	S	P	N	O
08steel	0.065	0.046	0.660	0.002 8	0.001 2	0.003 5	0.006 6
20Mn	0.200	0.270	1.230	0.004 3	0.006 1	0.008 0	0.012 0

The A_{r3} temperatures under different cooling rates were measured using DT1000 quenching dilatometer as presented in **table 2** to make suitable thermal-simulating scheme conduced on Gleeble-1500 simulator. The samples were machined for ϕ8 mm×15 mm or ϕ6 mm×12 mm. Thermal-mechanically processed samples were sectioned along compressing axes and the microstructures at middle position (where max. strain during inhomogenous compression is located) were analyzed.

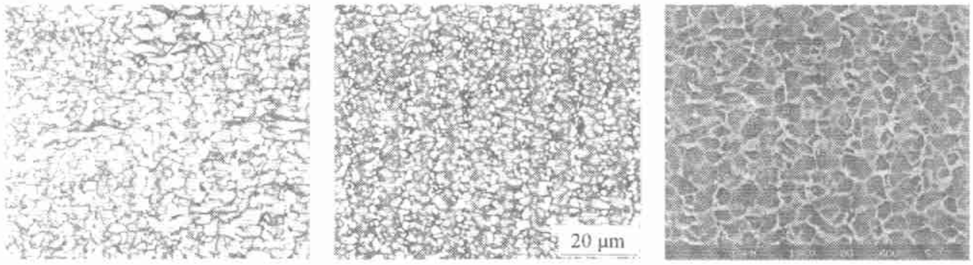
Table 2 Transformation temperatures during continuous cooling

Materials	t_A / ℃	Cooling rates / (℃·s^{-1})	A_{r3}/ ℃
08steel	930	20	740
		50	723
20Mn	890	5	725
		10	715
		20	700

3 Results and Discussion

3.1 Deformation at above A_{r3}

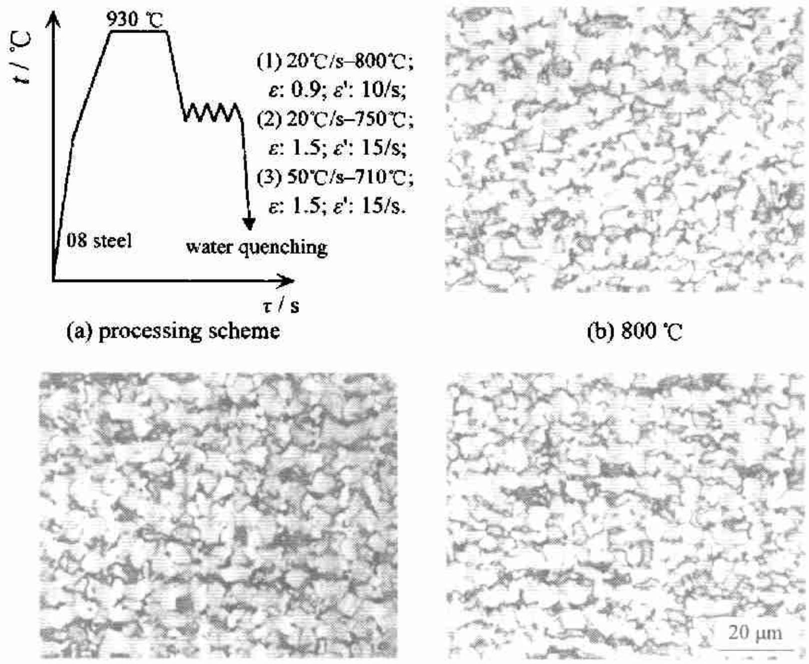
Here deformation at above A_{r3} deals with the ferrite dynamic transformation during deformation, i.e. strain induced transformation and not the simply austenite refinement through recrystallization. **Figure 1** shows the microstructures in a 08 steel deformed at 740 ℃. It can be seen that at strain 1 the strain induced transformation was complete and the ferrite grain size was ~3.5 μm; at strain 2 the ferrite was further refined due to the ferrite dynamic recrystallization. Despite of heavy strain during transformation, no trace of deformation was left on microstructures. The second phases in quenched samples were distributed either in the form of thin films around ferrite grains or in 'island' form (figure 1 (c)).



(a) $\varepsilon = 1$ (b) $\varepsilon = 2$ (c) SEM micrograph $\varepsilon = 2$

Figure 1 Further ferrite refinement through dynamic recrystallization in 08 steel, 940 ℃ heating, cooling with 50℃ /s to 740 ℃; strain rate: 15/s.

Figure 2 shows the simulating scheme and the obtained microstructures at different deforming temperatures (above A_{r3}) in 08 steel. It can be seen that in the range of selected deforming temperatures ferrite refinement can be realized effectively. Ferrite grains of ~4 μm can be easily obtained. The ferrite transformation in the 08 steel was less influenced by deformation temperature than that in 20Mn. However, the average grain size was larger (4–5 μm) than that in 20Mn.

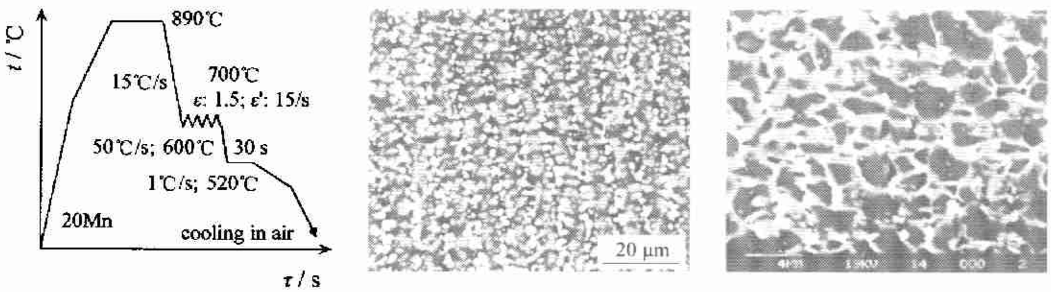


(a) processing scheme (b) 800 ℃

(c) 750 ℃ (d) 710 ℃

Figure 2 Microstructures obtained at different deforming temperatures.

Figure 3 gives the simulating scheme and the obtained structure in 20Mn. One can see that ultra-fine ferrite of ~2 μm can be obtained. Under single pass deformation no trace of deformation was left. No ferrite dynamic recrystallization was clearly detected according to grain size measurements at different strains [4]. From the quenched samples it is known that the ferrite volume fraction strain-induced in 20Mn was very limited and fast cooling will not result in ferrite + pearlite structure. By controlled cooling fine ferrite + pearlite structures can be achieved. Ferrite grains did not grow significantly. The real reduction was 68% and not 77% ($\varepsilon = 1.2$). Under high magnification in SEM many Fe_3C particles formed which may be resulted either by the



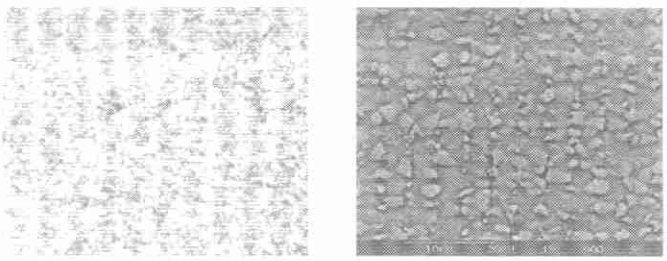
(a)processing scheme (b) microstructure (c) SEM micrograph

Figure 3 Influence of cooling after deformation in 20Mn.

crashing of layered pearlite or degenerated form of pearlite due to the deformation of austenite.

From **figure 4** it is obvious that deformation temperature exerted strong influence on ferrite volume fraction. According to the measurement of phase transformation temperature, the A_{r3} at cooling rate 10 ℃/s is 715℃, indicating that deforming temperature of 780 ℃ was high above A_{r3}. At 780 ℃, ferrite could only form at austenite grain boundaries. Therefore, the key factor for microstructure control is to raise ferrite volume fraction. As deforming temperature decreased, the ferrite volume fraction increased (figure 4(c), (d)). Compared with 08 steel the ferrite grains strain-induced in 20Mn were clearly smaller with a mean size of ~2 μm.

(a) processing scheme (b) 780 ℃ (c) 740 ℃



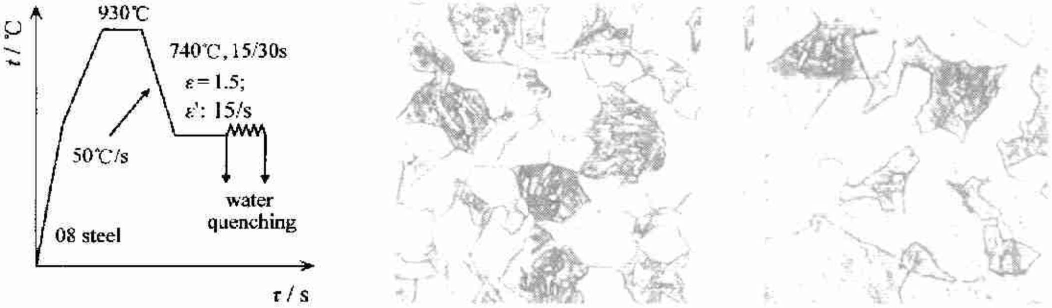
(d) 700 ℃ (e) strain rate 1/s, 750 ℃

Figure 4 Microstructures obtained at different deformation temperatures in 20Mn.

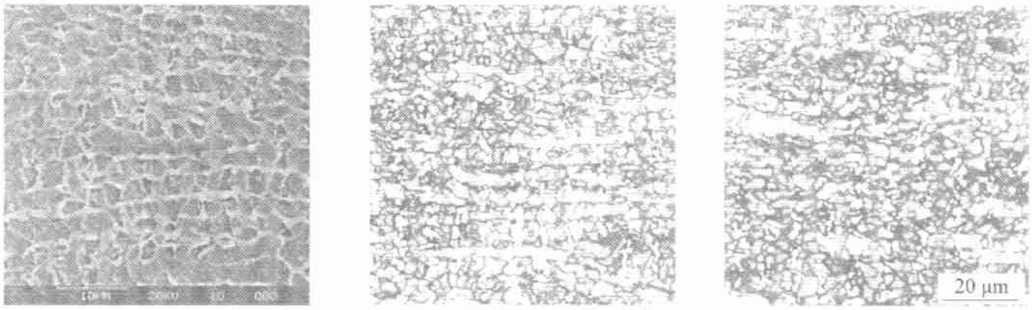
3.2 Deformation in two-phase region of (α+γ)

Figure 5 illustrates the microstructures processed in two-phase region of 08 steel and its corresponding simulating scheme. The samples were hold at 770 ℃ for 15 s and 30 s and the ferrite volume fractions were nearly same (>50%). Unlike the deformation at above A_{r3} which mainly introduced strain induced transformation and ferrite dynamic recrystallization took place after strain induced transformation. Here, both strain induced transformation and ferrite dynamic recrystallization occurred concurrently. The carbon content in untransformed austenite should be higher than the average value, therefore the strain-induced ferrite was finer, but ferrite dynamic recrystallization occurred unevenly depending on the orientation of ferrite grains.

From the magnified micrograph in SEM (figure 5 (d)) it can be seen that in some elongated grains no clear grain boundaries were formed. Since the second phases around deformed pro-eutectic were also arranged in elongated form, the trace of deformation can be never eliminated regardless of to what extent ferrite recrystallized dynamically. Although pro-eutectic ferrite recrystallized to a large extent, some large deformed ferrite grains can still be seen indicating that ferrite grain size distribution is rather uneven. With EBSD (Electron Back-Scattering Diffraction) technique the extent of dynamic recrystallization can be quantitatively de-



(a) processing scheme (b) holding 15 s, then quenching (c) holding 30 s, then quenching



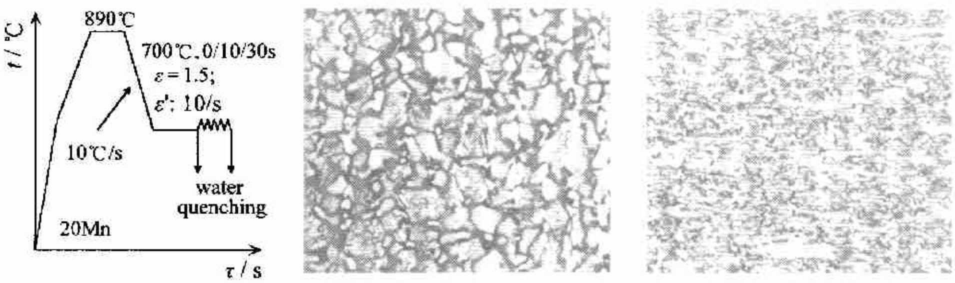
(d) SEMmicrograph, holding 30 s, then deforming (e) holding 15 s, then deforming (f) holding 30 s, then deforming

Figure 5 Microstructure obtained during deformation at two phase-region in 08 steel.

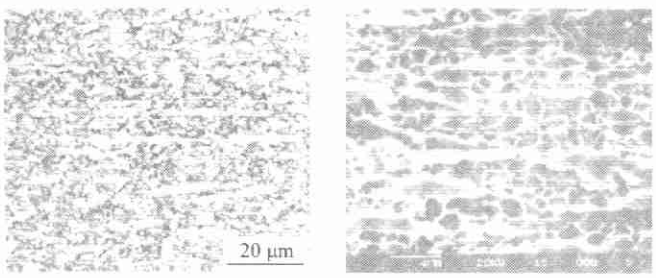
scribed.

Figure 6 illustrates the microstructures obtained in the two-phase region of 20Mn steel and its corresponding simulating scheme. After a holding of 30 s equal-axial ferrite formed and upon deformation, elongated ferrite was resulted, however, no clear dynamic recrystallization was observed like that in 08 steel. The strain-induced ferrite from carbon-enriched austenite was very fine (~1 μm). It was reported [5] that in a steel of 0.17%C, 1.35%Mn, deformation of 80% reduction in two phase region leads to a dynamic recrystallization of pro-eutectoid, however, the austenite was kept untransformed (the holding time was 30 min.). It is well known that Mn decreases the A_{r3} and enhances the volume fraction of pearlite. This may result in the restriction of transformation of austenite to ferrite, however, the existed results indicate that in Q235 steel even a deformation at 900 ℃ can produce ferrite [6]. Thus the reason should be the slower diffusion of Mn atoms.

To decrease the pro-eutectic ferrite grain size by fast



(a) processing scheme (b) holding 30 s, then quenching (c) holding 30 s, then deforming



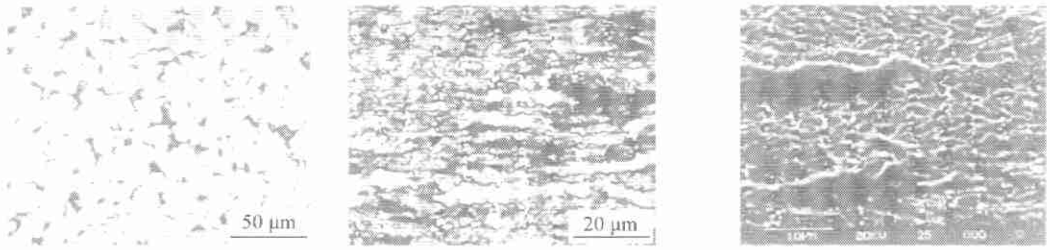
(d) holding 10 s, then deforming (e) SEM micrograph, holding 30 s, then deforming

Figure 6 Microstructure obtained during deformation at two-phase region in 20 Mn.

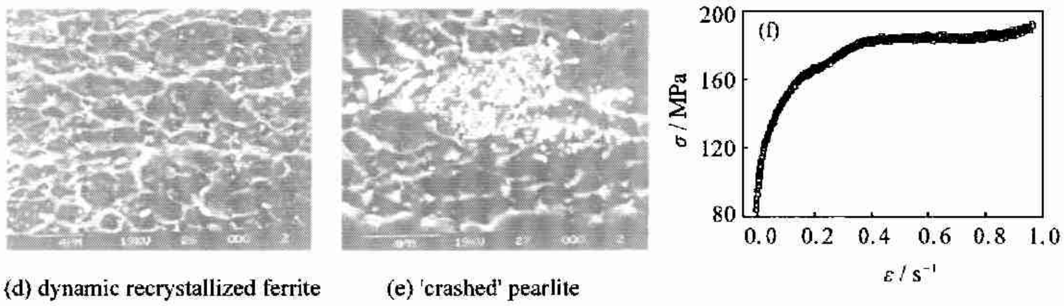
cooling can improve the inhomogeneity between two types of grains, namely, those by strain induced transformation and those by dynamical recrystallization of pro-eutectic ferrite.

3.3 Deformation at below A_1

Deformation at below A_1, at which no transformation will take place, can refine ferrite grains entirely through ferrite dynamic recrystallization. **Figure 7** shows the microstructure obtained from 08 steel heated from room temperature and deformed at 700 ℃ at a strain rate of 0.1/s. This strain rate was selected because a lower strain rate usually activates dynamic recrystallization more easily than a higher one, although finer grains are normally obtained in later case at a fixed temperature. It is obvious that ferrite dynamic recrystallization has occurred at strain of 1, but only partially. The measured σ-ε curve did not reveal recrystallization clearly (figure 7 (f)).



(a) initial microstructure (b) optic microstructure after deformation (c) partial dynamic recrystallization



(d) dynamic recrystallized ferrite (e) 'crashed' pearlite

Figure 7 Microstructures formed due to the deformation at 700 ℃, strain rate 0.1/s, 08 steel.

Although fine ferrite grains of ~2 μm were observed in some regions, no new grains were formed within other old grains (figure 7 (c)). The reason is that the orientations of these grains were stable against compression. In addition pearlite in lamellar form were crashed due to deformation (figure 7 (e)). If strain increased further crashed Fe_3C particles would be arranged in string form together with further ferrite refinement. It is not clear that to what extent the new grain boundaries between fine grains within large deformed grains were large angle ones and this deserves quantitative analysis by means of EBSD (Electron Back-Scattering Diffraction) technique. The less effective refinement below A_1 is attributed to the large initial ferrite grain size, the large pearlite cells and perhaps the low deforming temperature.

Since 20Mn contains a higher volume fraction of pearlite and thus possesses high deformation resistance, it is not suitable to deform it at below A_1. **Figure 8** compares the ferrite refinements achieved by deformation at different temperatures and their corresponding mechanisms.

4 Conclusions

(1) The microstructure obtained through strain induced transformation at above A_{r3} is more uniform. Dynamic recrystallization of ferrite after strain induced transformation can further refine ferrite grain size in 08 steel. No trace of deformation was left after heavy strain. Deforming temperature above A_{r3} mainly influenced ferrite volume fraction in 20Mn.

(2) Deformation in two-phase region of (α+γ) led to two separate events, namely, dynamic recrystallization of pro-eutectic ferrite and strain induced transformation from untransformed austenite. Ferrite dynamic recrystallization took place more easily at lower carbon content than at higher carbon content. However, inhomogeneity in microstructure existed during deformation at this temperature range.

(3) Ferrite dynamic recrystallization can occur during deformation at below A_1 and fine ferrite can be obtained through recrystallization. However, due to the difference of orientations some grains were more sluggish to recrystallize dynamically. The microstructure is

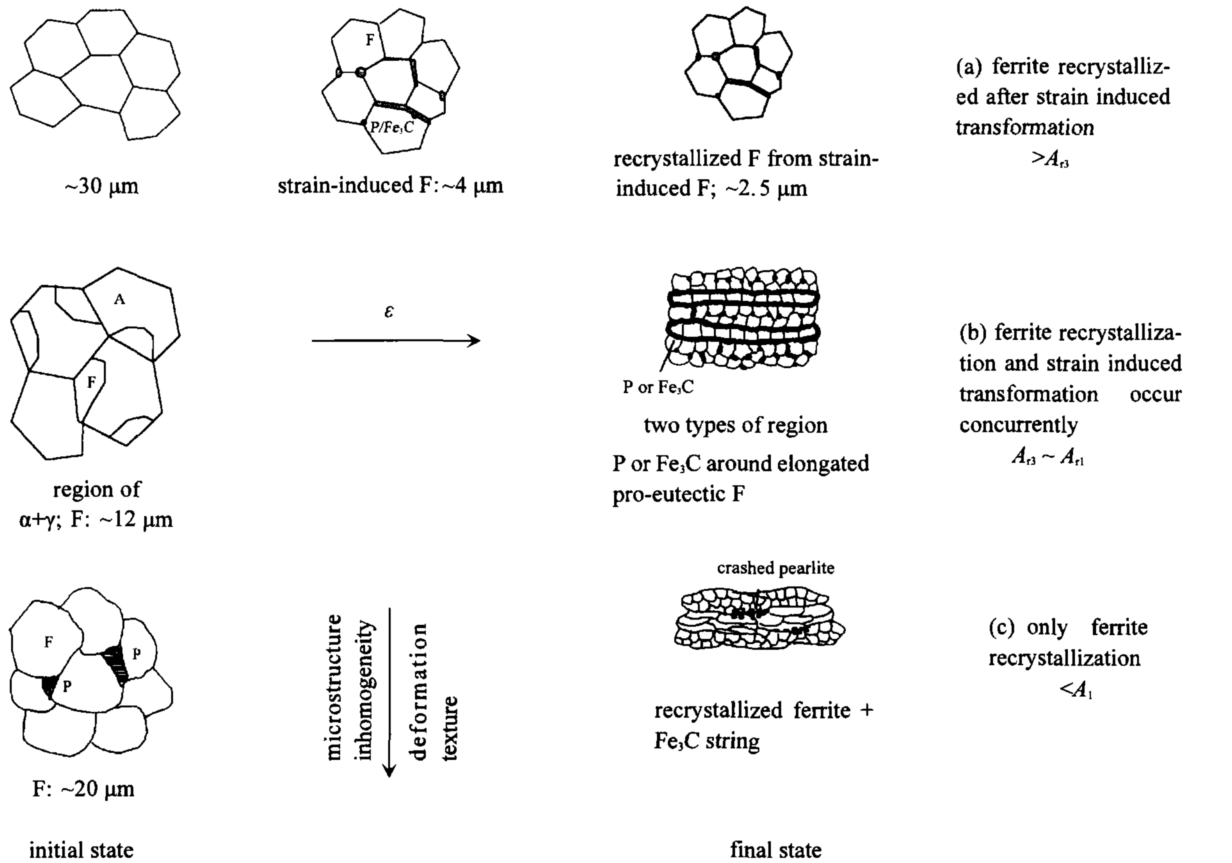


Figure 8 Schematic summary of ferrite refinements processed at different temperatures, A: austrtenite; F: ferrite; P: pearlite.

not entirely uniform and the trace of deformation is always retained.

References

[1] H. Yada, Y. Matsumura, K. Nakajima: *United States Patent*, Patent No. 4466842, 1984.

[2] Y. Matsumura, H. Yada: *Transactions ISIJ*, 27 (1987), p. 492.

[3] A. Najah-Zadeh, J. J. Jonas, S. Yue: *United States Patent*, Patent No. 5200005, 1993.

[4] P. Yang, F. Cui, F. Wang: *J. of University of Science and Technology Beijing*, 8 (2001), p. .

[5] K. Watanabe: *Tetsu-to-hagane* (in Japanese), 71 (1985), p. 1926.

[6] P. Yang, Y. Fu, F. Cui, Z. Sun: *Acta Metall. Sin.* (in Chinese), 37 (2001), No. 6, p. 601.