Development of High Strength Steels utilizing interphase precipitation

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- Hot-rolled ferritic steel precipitate-strengthened by ultra fine carbides in row
- Feature of nanometer-sized carbides in row
- Carbides formation during $\gamma \rightarrow \alpha$ transformation
- Thermal stability of nanometer-sized carbides

Hot-rolled steel sheet strengthened with interface precipitated ultra fine carbides

(1)Ferrite matrix

(No pearlite, no large cementite)

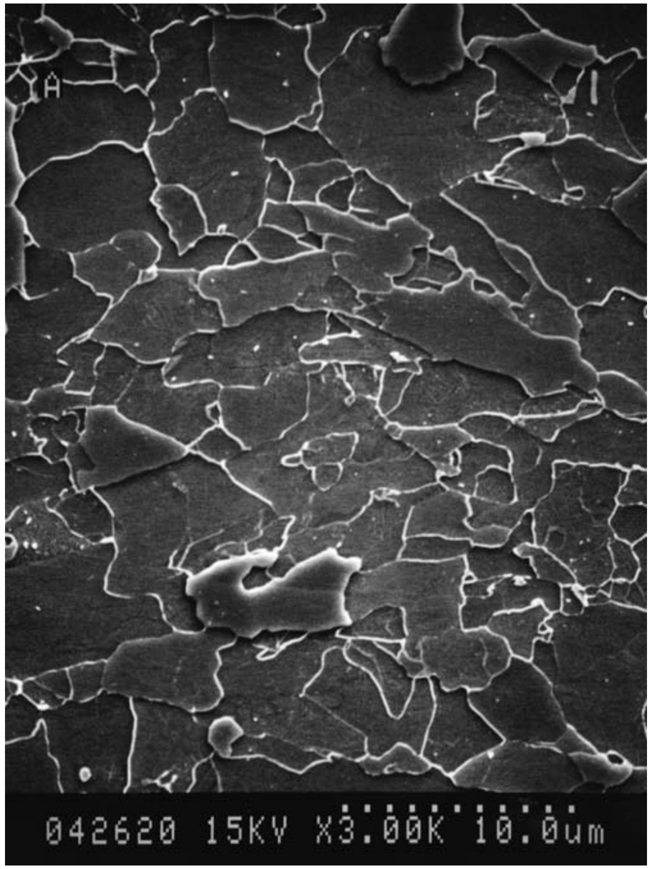
(2)Very fine carbides

- Amount of precipitation-strengthening

→more than 200MPa.

(conventional steel: about 100MPa)

- Excellent thermal stability



Chemical composition:

0.04%C-0.2%Si-1.6%Mn-0.08%Ti-0.2Mo

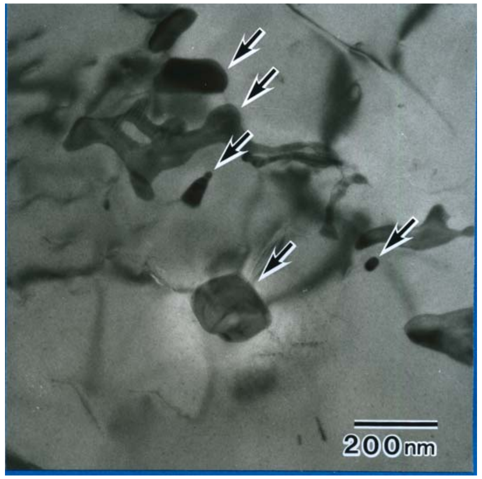
Ultra fine carbides

Ferrite matrix

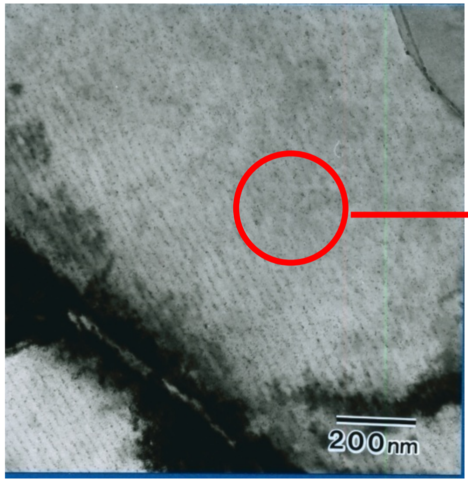
Uniform carbides by interface precipitation

Ultra Fine carbide (Ti,Mo)C (No report in the past.)

0.04%C−0.2%Si−1.6%Mn−0.08%Ti−0.2Mo

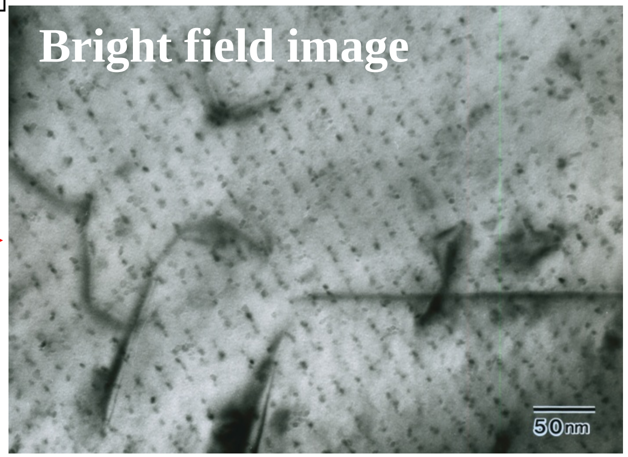


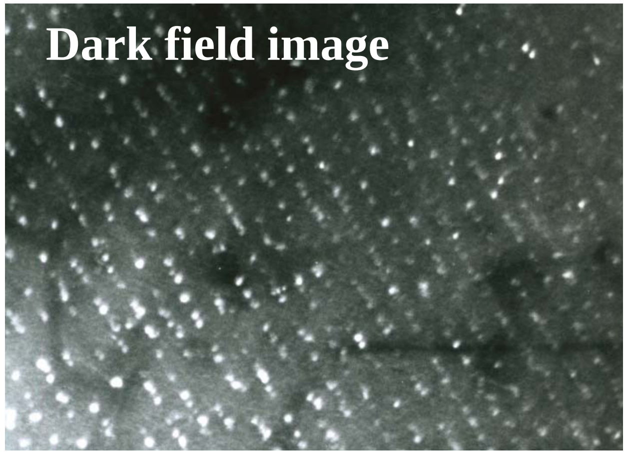
Conventional carbides



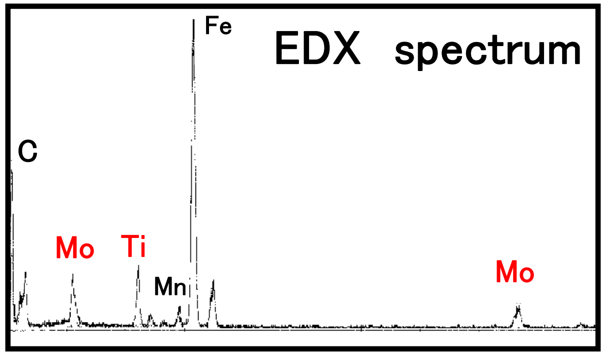
Ultra fine carbide

TEM micrographs

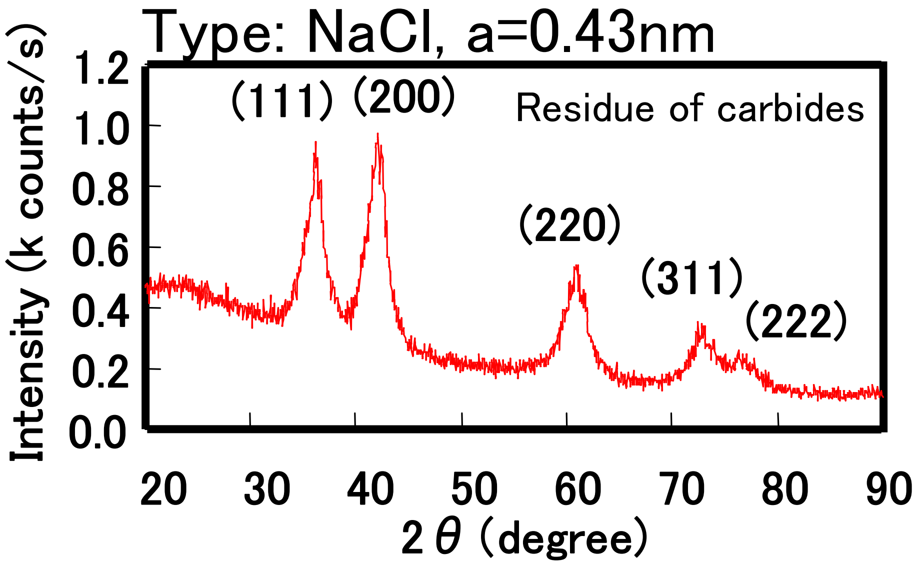


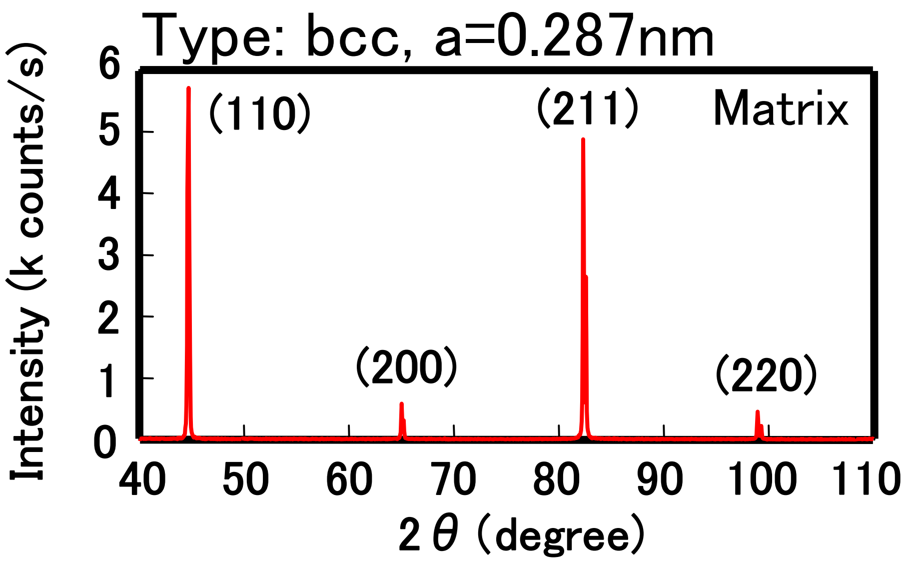


(Defocus method)



Lattice structure of ultra fine carbide

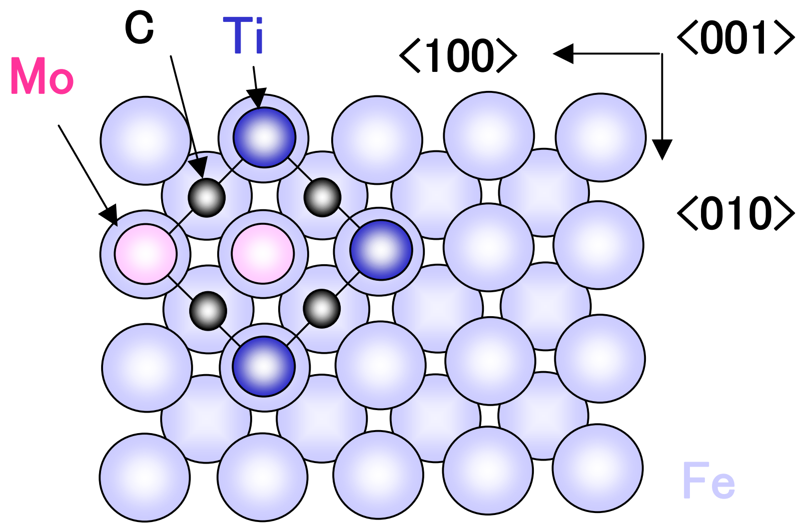




Baker-Nutting relationship

$(100)_{carbide}//(100)_{\alpha}$

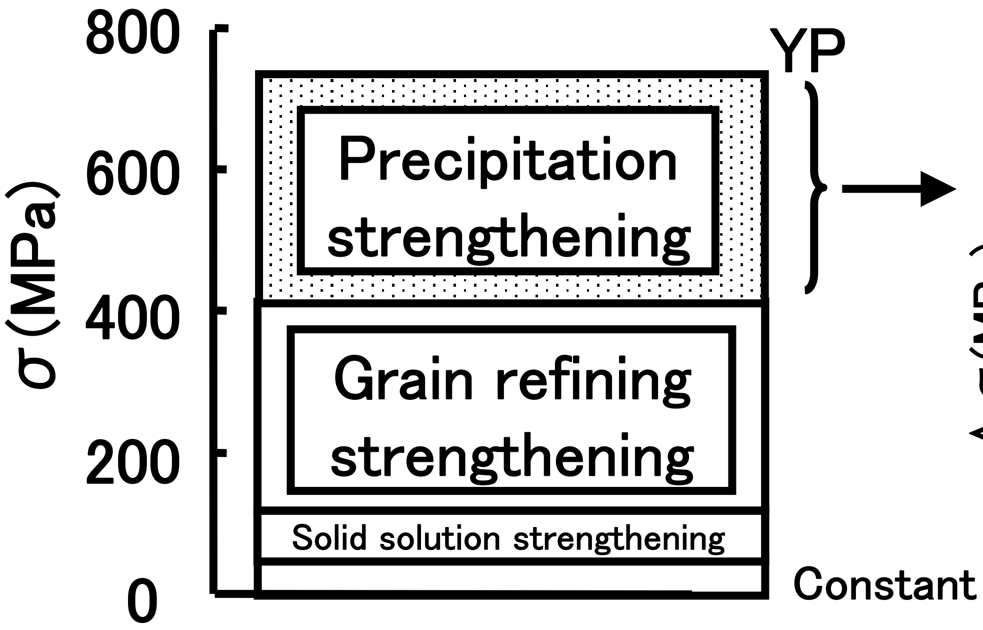
$\langle 010\rangle_{carbide}//\langle 011\rangle_{\alpha}$



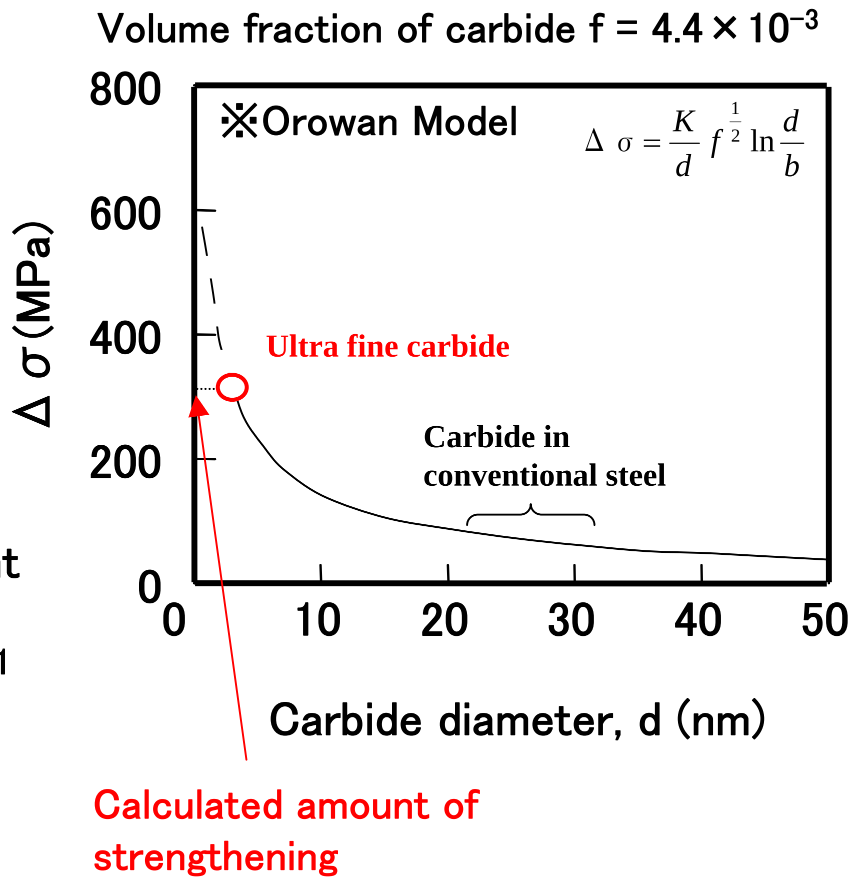
Relationship between lattice of carbide and that of ferrite matrix

Amount of strengthening by ultra fine carbide

Chemical composition ：0.04%C−0.2%Si−1.6%Mn−0.08%Ti−0.2Mo



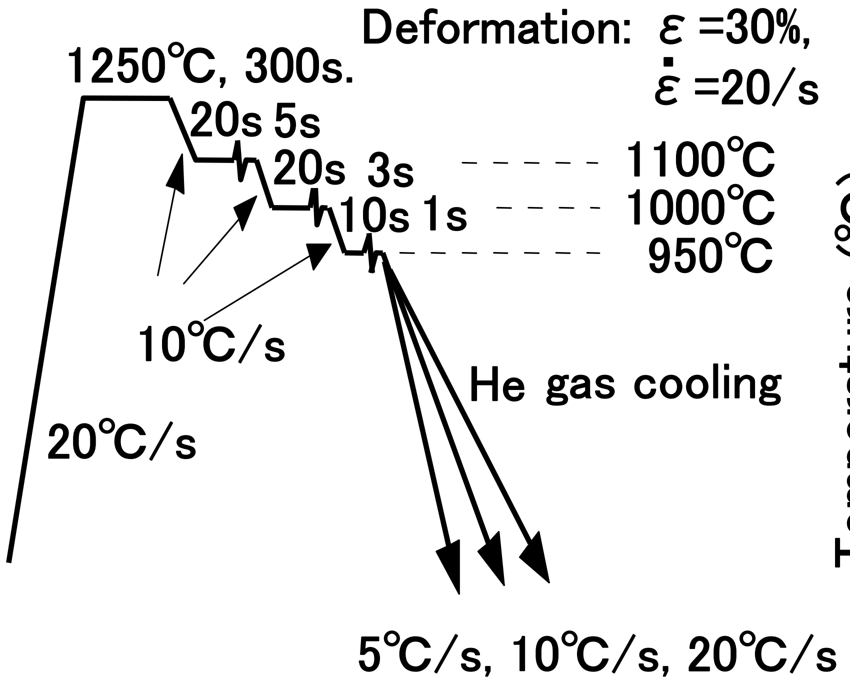
σ(MPa)=53.9+32.34[%Mn]+83.16[%Si]+354.2[%N]+17.402×$d^{-1/2}$, d: ferrite grain diameter ※1

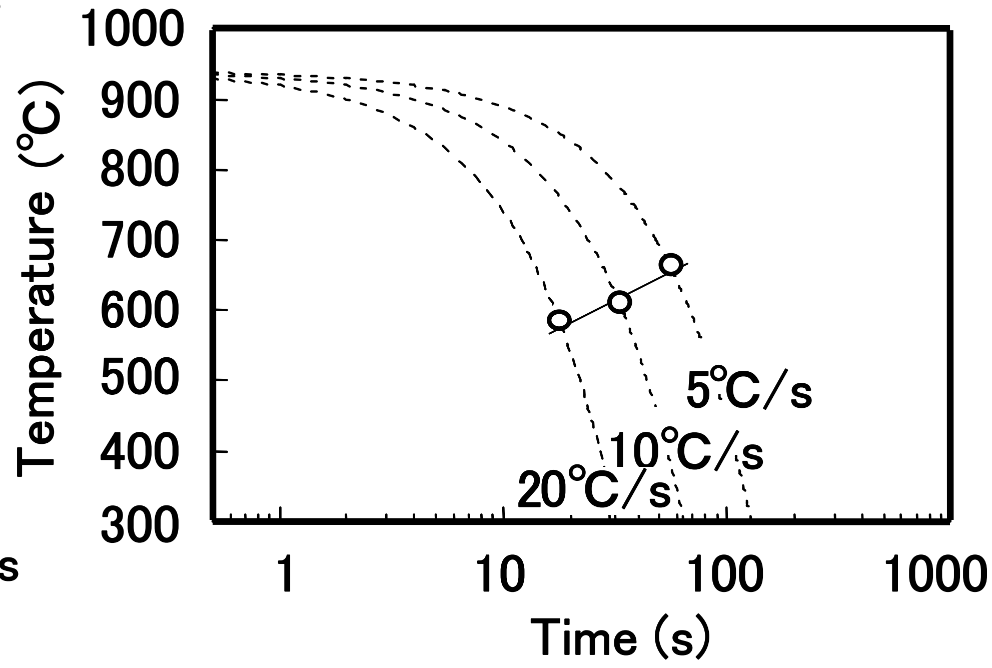


※1 F. B. Pickering: Physical Metallurgy and The Design of Steels, APPLIED SCIENCE PUBLISHERS LTD., London, (1978),63.

Transformation temperature

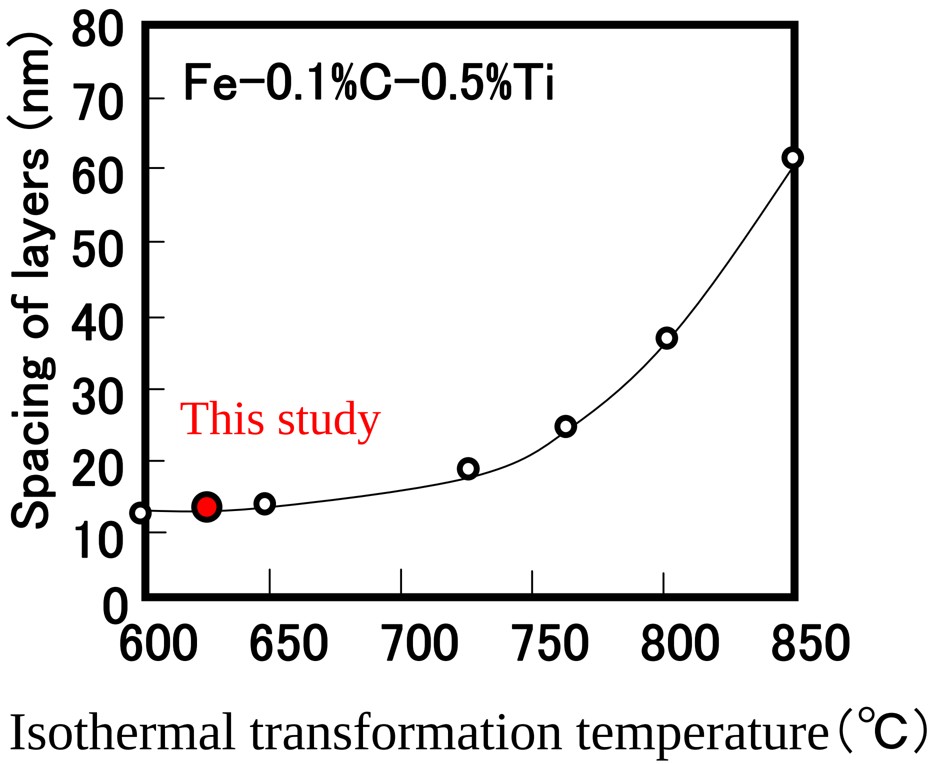
Chemical composition :0.04%C–0.2%Si–1.6%Mn–0.08%Ti–0.2Mo

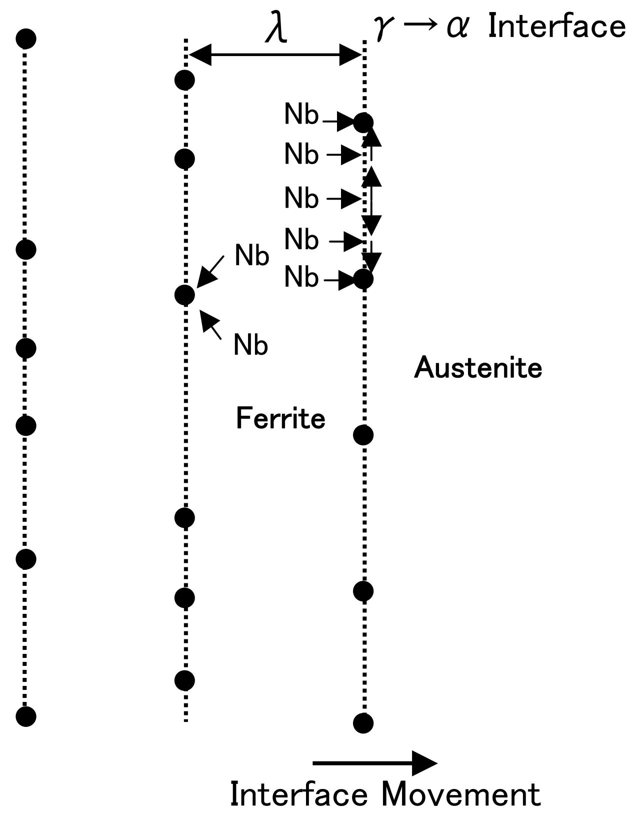




Ar_3 transformation temperature is in the range from 600℃ to 650℃.

Spacing between layers of TiC





In the case of NbC、Model after Gray

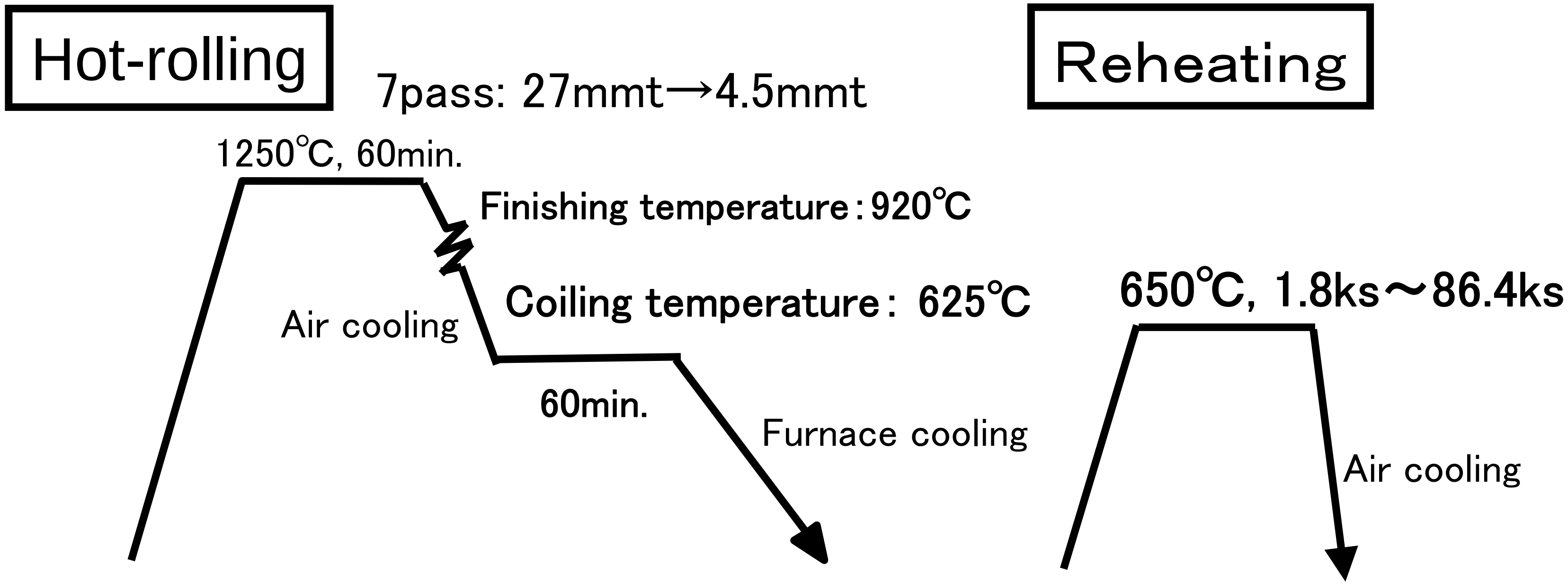
S.Freeman; ISI Special Report No.145,(1971), 152.

J.M.Gray and R.B.G.Yeo; Trans. ASM, Vol.61(1968), 255.

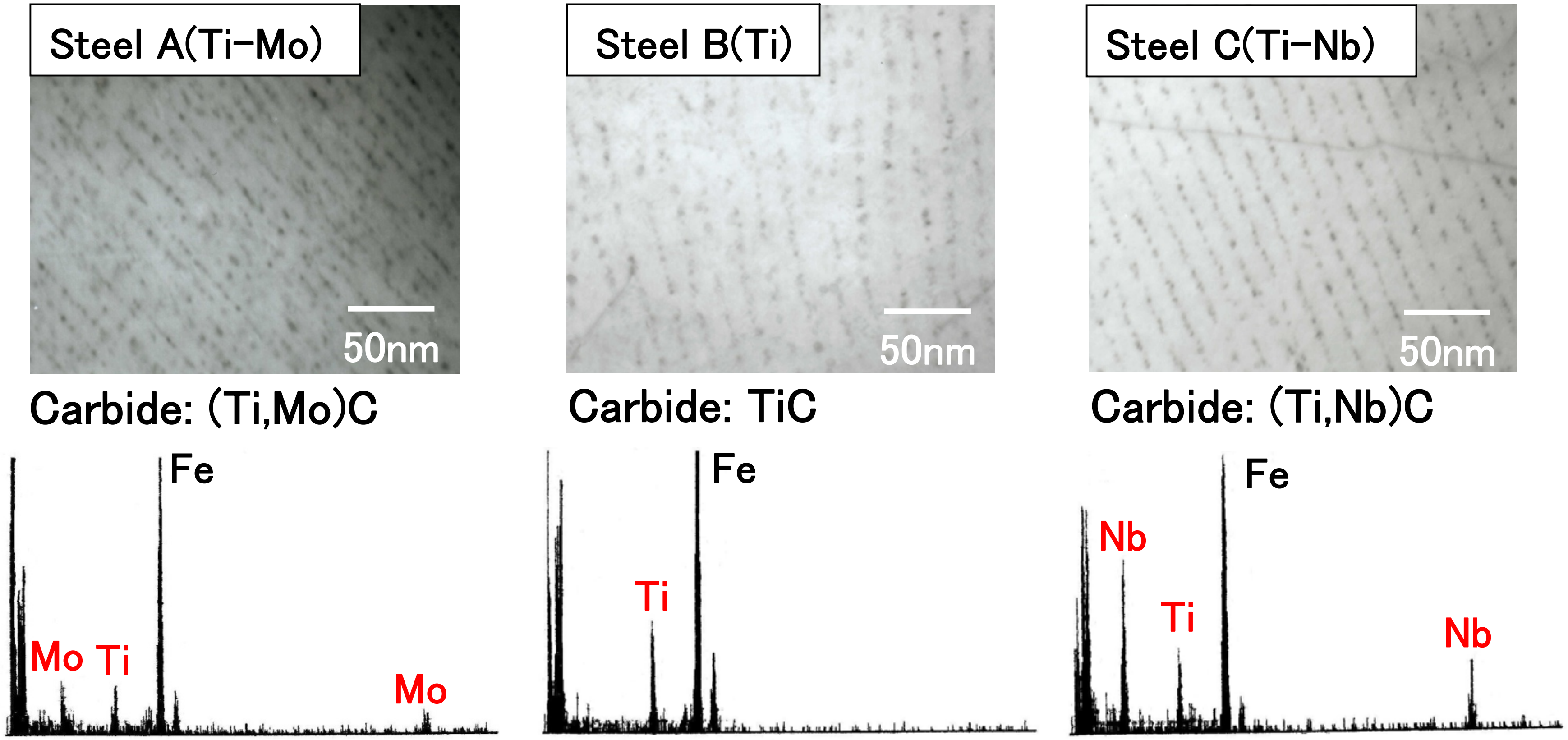
Experimental procedure

Table Chemical compositions of steels investigated(mass%).

	C	Si	Mn	P	S	N	Ti	Mo	Nb
Steel A	0.04	0.01	1.3	0.005	0.001	0.0025	0.1	0.2	–
Steel B							0.2	–	–
Steel C							0.1	–	0.18
Steel X							tr	0.2	–
Steel Y							0.1	–	–

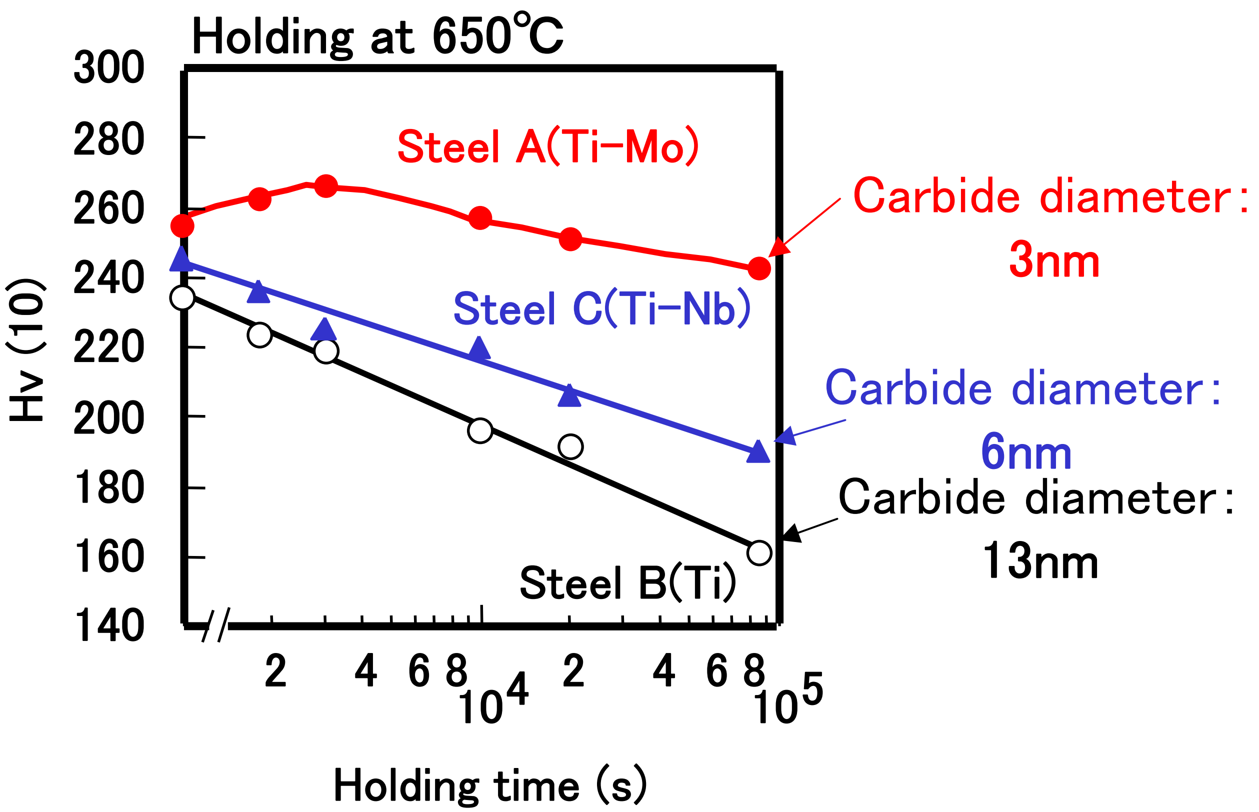


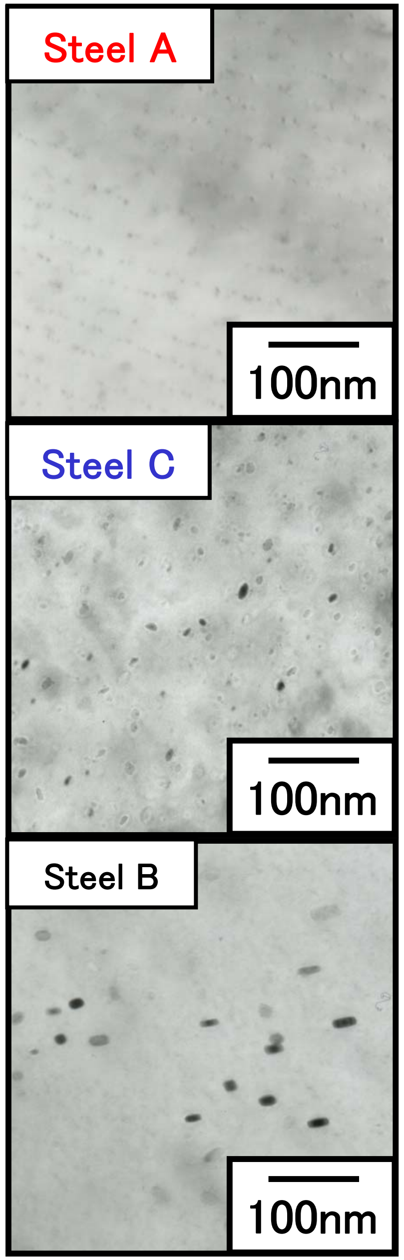
Ultra fine carbide in samples



- Lattice structure: **NaCl type**
  - Relationship for matrix : $\{100\}_{carbide}//\{100\}_{\alpha}$, $\langle 110\rangle_{carbide}//\langle 100\rangle_{\alpha}$ (Baker-Nutting)

Change in hardness with heating at 650℃





Ostwald ripening

Ostwald ripening

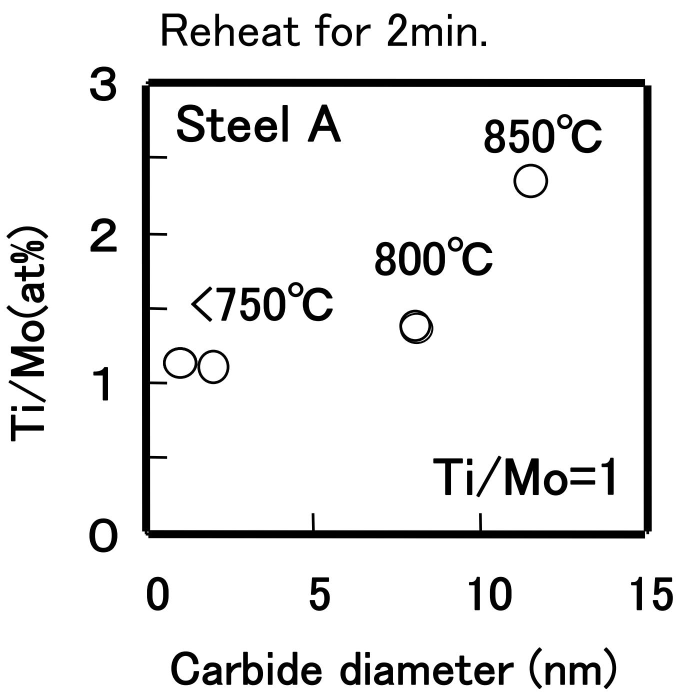
$$r^3 - r_0^3 = \left(\frac{8\gamma D C_\infty \Omega^2}{9RT} \right) t^3$$

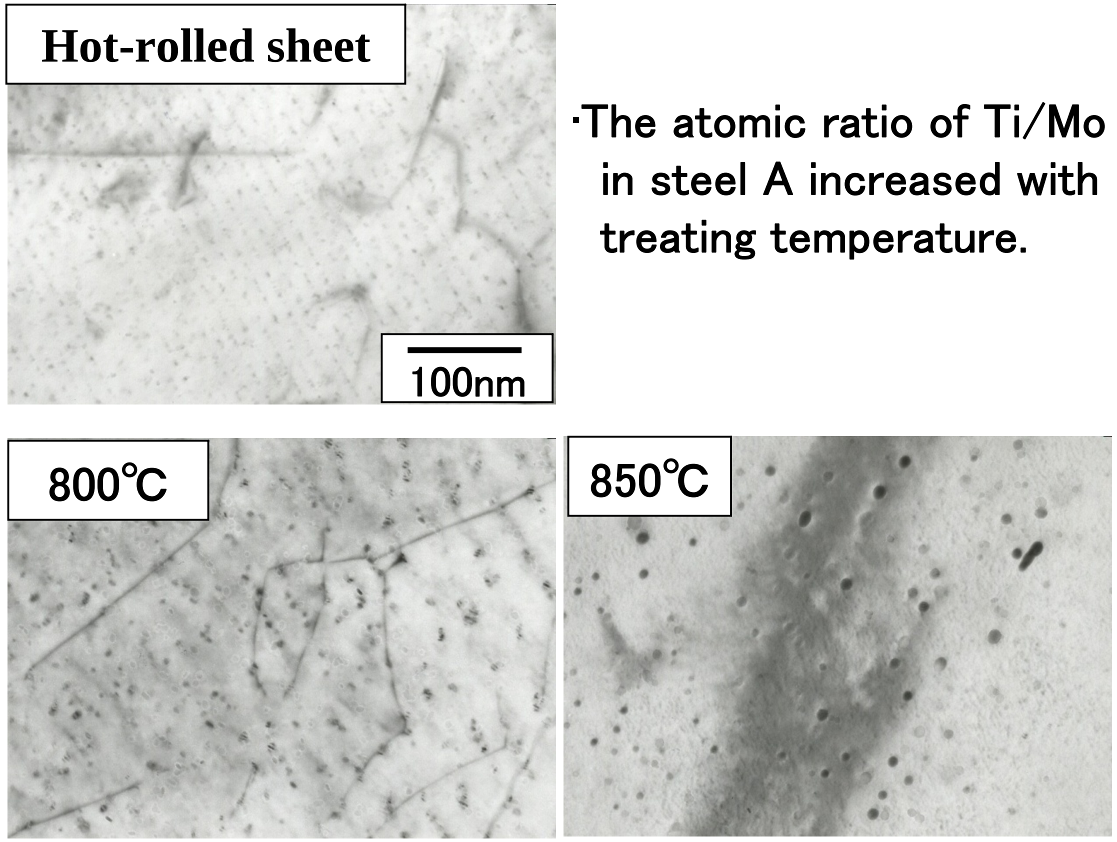
r：carbide diameter after coarsening、r0：carbide diameter before coarsening、
R：Gas constant、 T：absolute temperature
γ：interfacial energy、D：diffusion coefficient、
C_∞：concentration of solid solution element、Ω：volume of 1mol

No influence of Mo on carbide formation directly

- **Diffusion coefficient** → **No difference between steels**
- **Interfacial energy between carbide and matrix**
- **Amount of solid solution element**

Carbide coarsening by high temperature heating



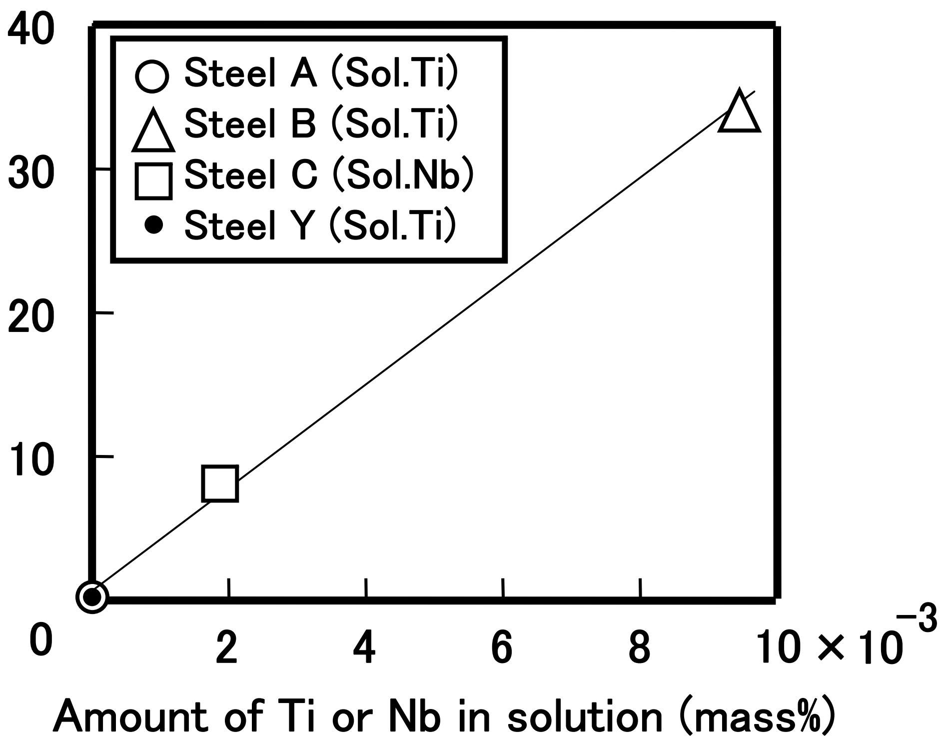


·The atomic ratio of Ti/Mo in steel A increased with treating temperature.

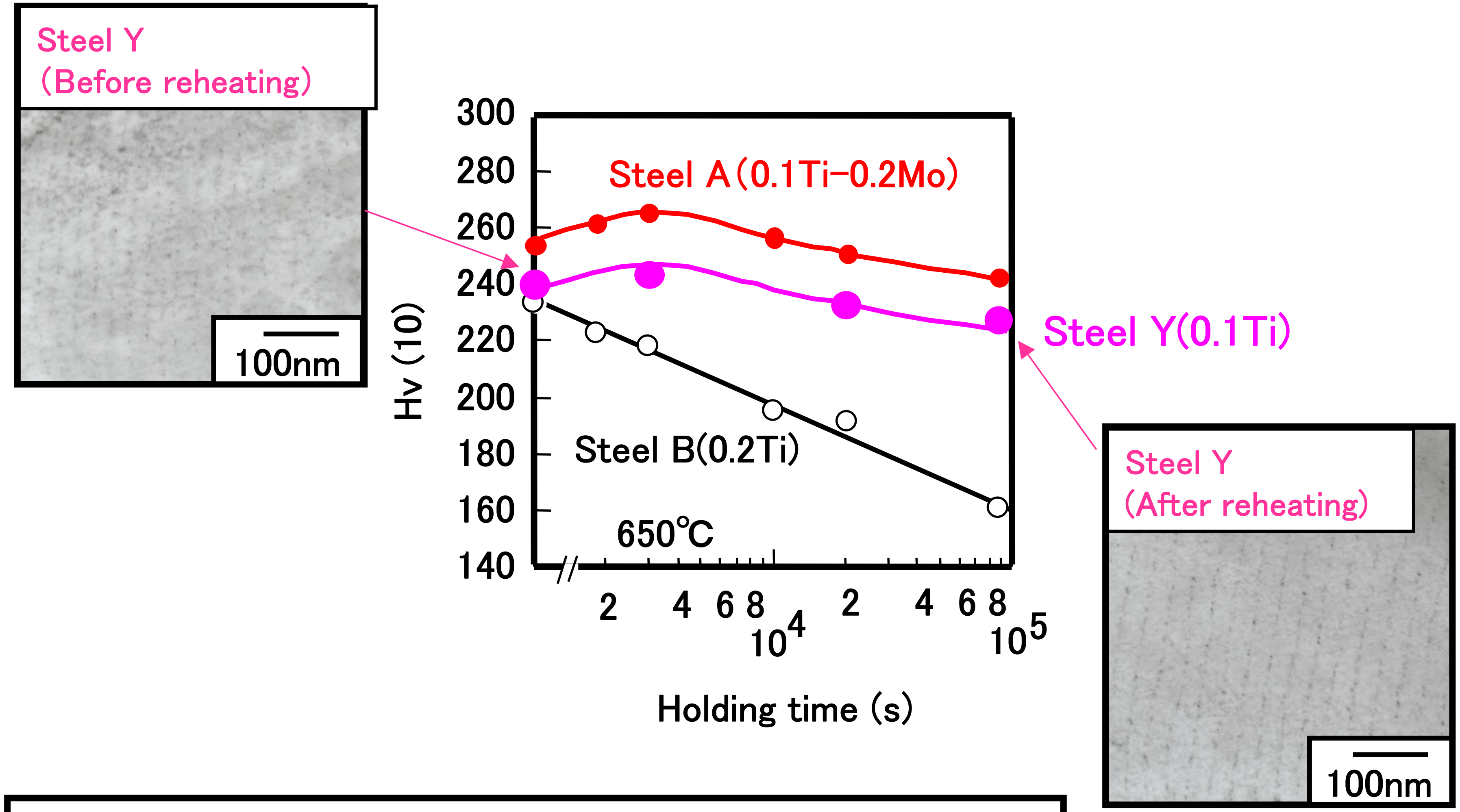
▪Composition of carbide in steel A changed while that in steel C did not change.

Relationship between amount of carbide former and the rate of coarsening

$$\frac{9RT}{8}\frac{(r^3 - r_0^3)}{Dt\Omega^2}$$



Retarding of carbide coarsening by controlling of amount of Ti in solution.



Carbide in steel Y (Ti in solution is reduced) exhibited the thermal stability as same as that in steel A.

Fin.