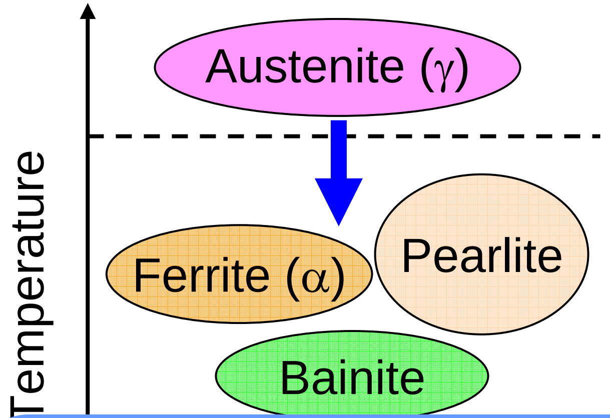
Reverse transformation kinetics from tempered martensite structure in high carbon steels

Goro Miyamoto, Tadashi Furuhara

Institute for Materials Research,
Tohoku University, Japan

Background - Reverse transformation to austenite (γ)



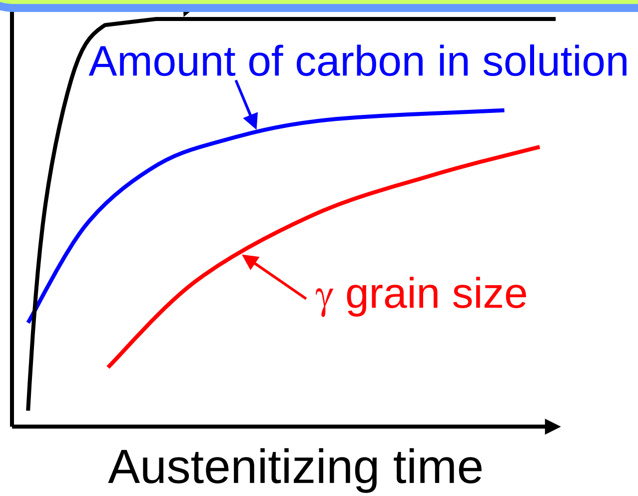
Fine γ produces fine transformation products.

→γ refinement is effective method to refine transformed products.

Reverse transformation has been

Objective

To investigate effect of substitutional alloying elements on reverse transformation kinetics from tempered martensite.



- Reverse transformation treatment should be finished before coarsening of γ grain.
- A certain amount of θ should be dissolved for hardening process to obtain hard martensite.

Understanding of kinetics of reverse transformation and θ dissolution is necessary.

Experimental (preparation of initial structures)

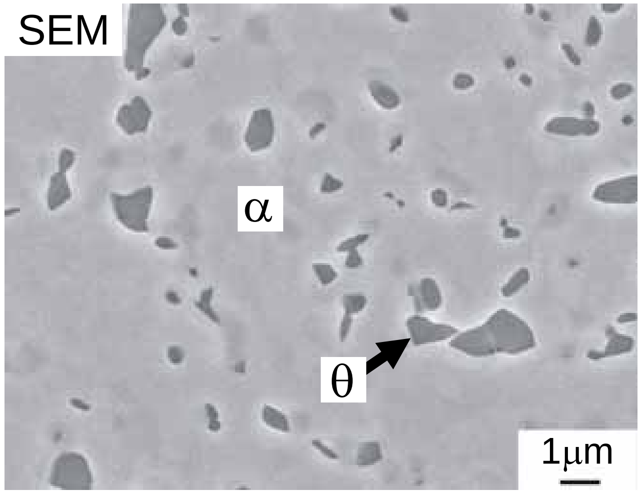
● Alloys Fe-0.6C, Fe-0.6C-M (M = 1Mn, 1Si, 1Cr) (mass%)

● Preparing sample for reverse transformation

Austenitizing (1273K, 1.8ks) → W.Q. → Tempering at 923K for various time

● Characteristics of initial structures

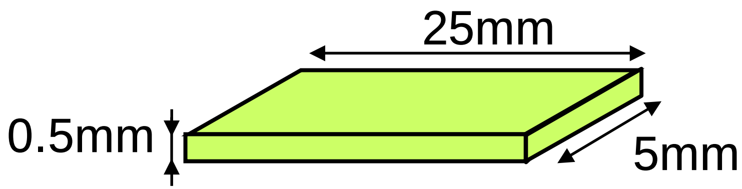
0.6C alloy tempered for 1.5h



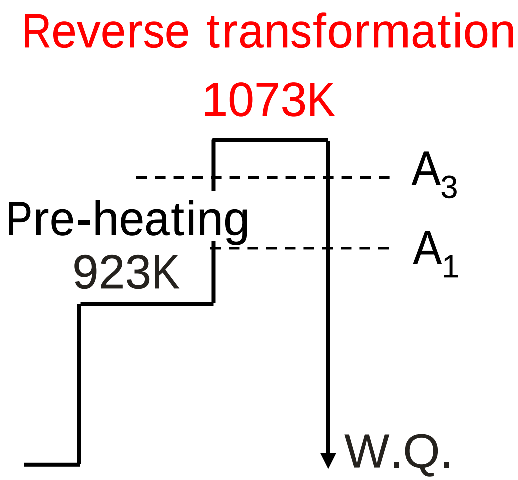
alloy	0.6C	1Mn	1Si	1Cr
Tempering time at 923K (h)	1.5	72	5.5	720
Average θ diameter (μm)	1.3	0.95	0.95	0.99

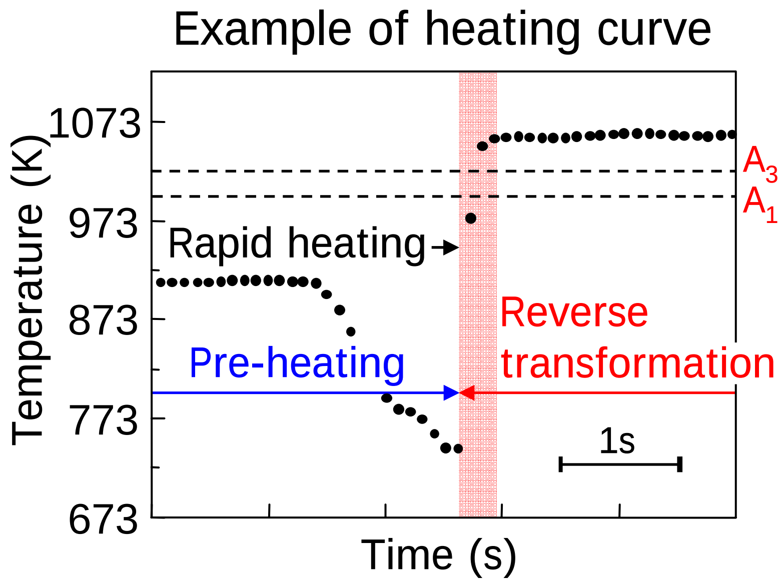
Experimental (reversion treatment & characterization)

●Specimen size



●Reverse transformation

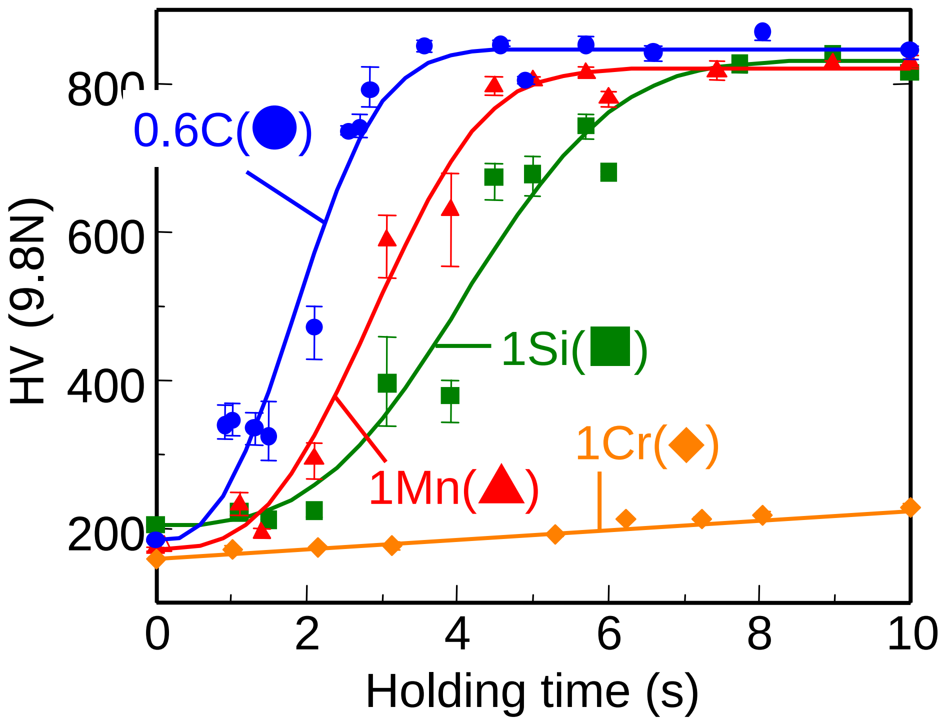




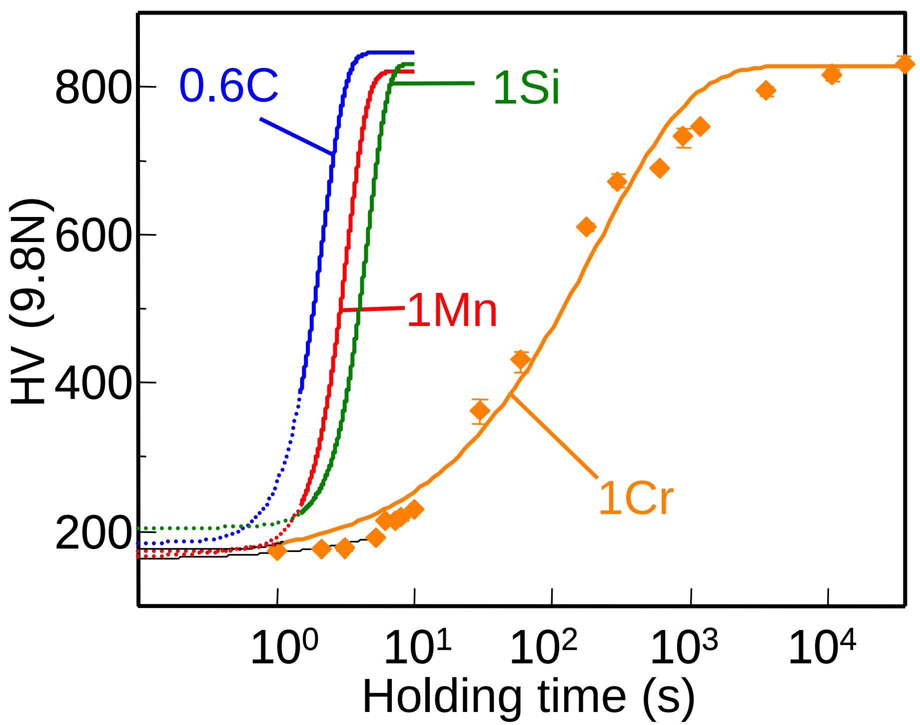
●Microstructure characterization   OM, SEM, TEM

●Vickers hardness measurement (9.8N)

Alloying effect on variation in Vickers hardness



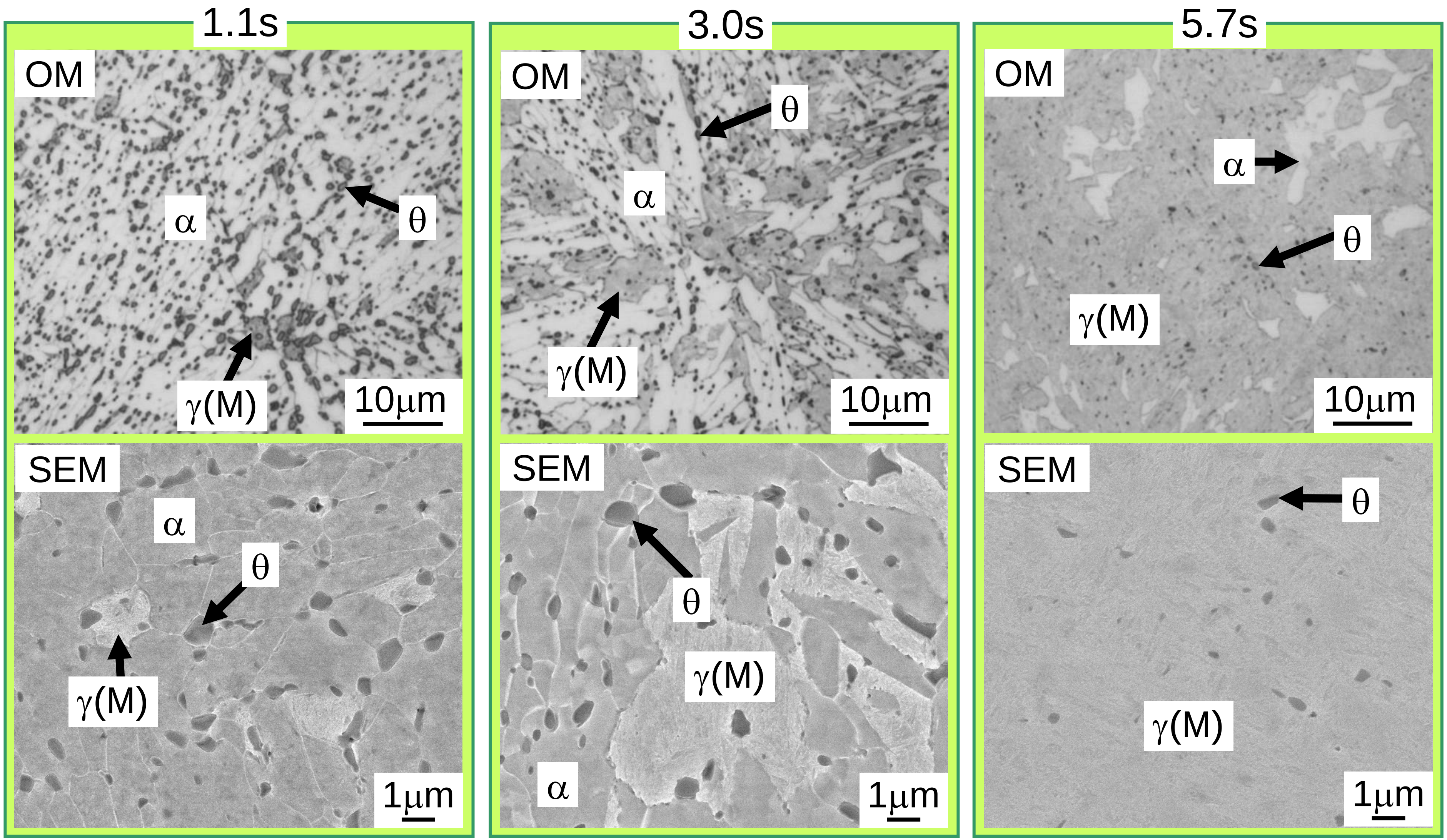
Reverse transformation at 1073K



Addition of alloying elements retards hardness increase.
Hardness change of 1Cr alloy is extremely slow.

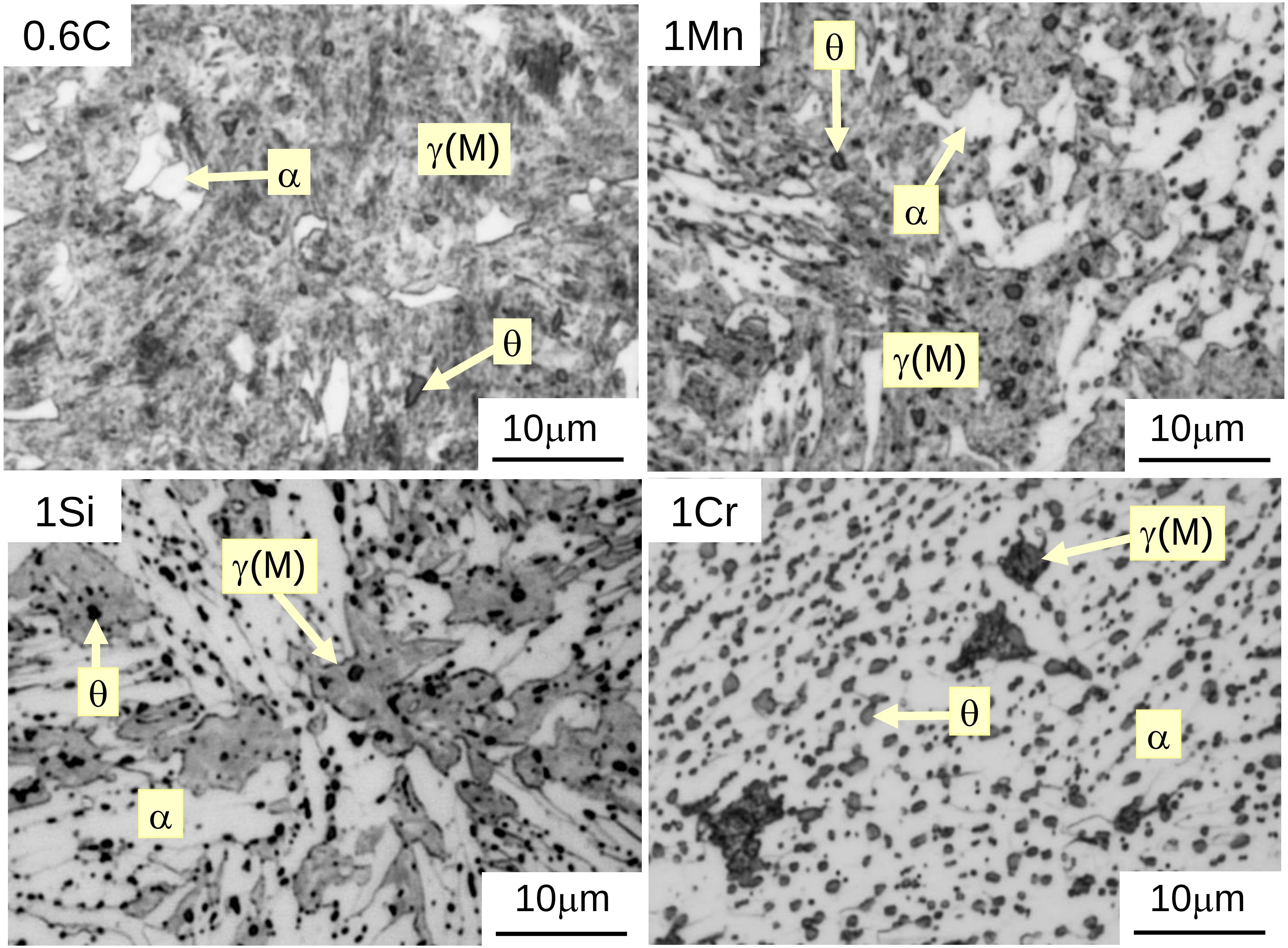
Microstructure change during reverse transformation

<u>1Si alloy, reverse transformation at 1073K</u>



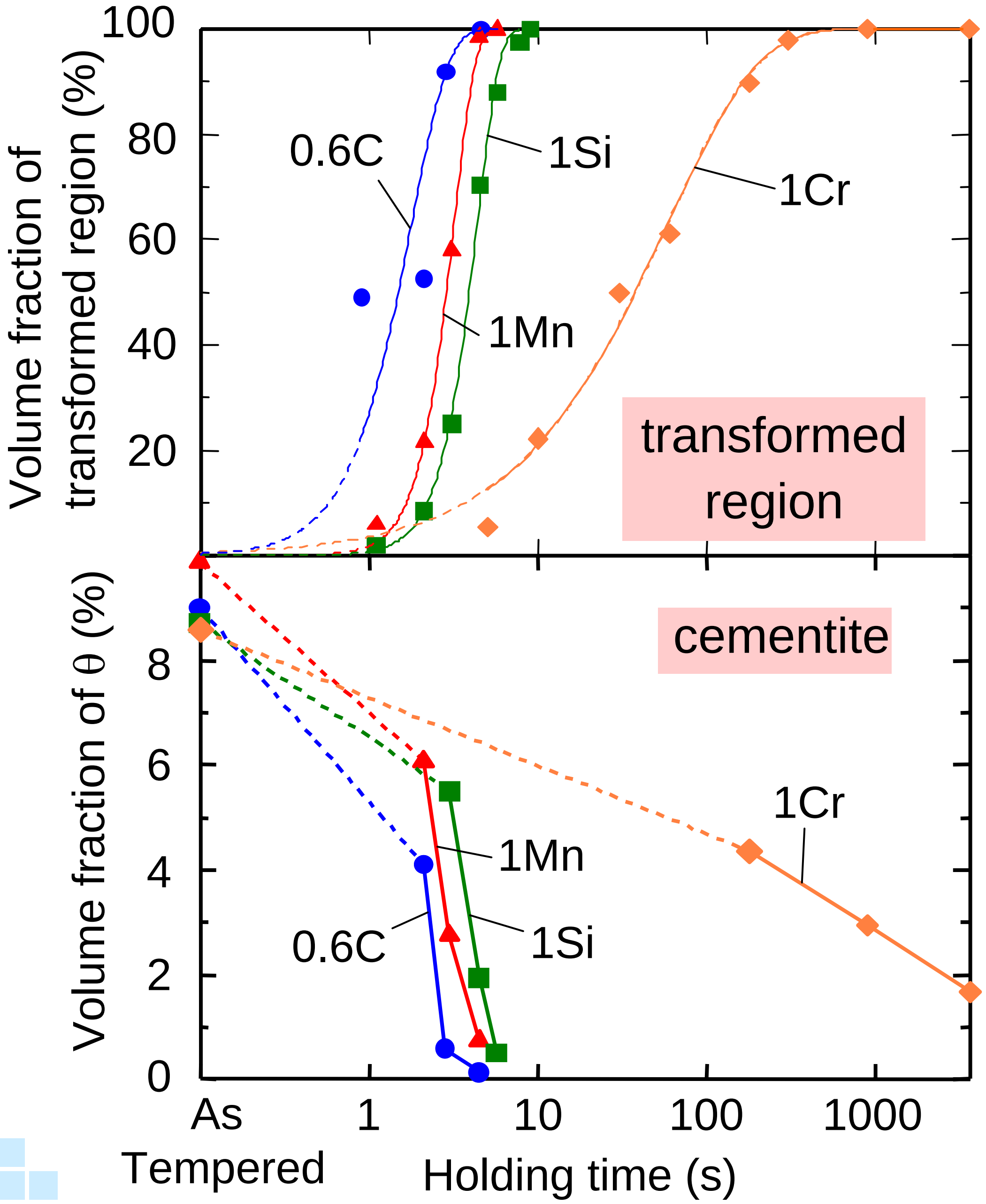
α：ferrite γ(M)：martensite transformed from austenite θ：cementite

Reversely transformed microstructure at 1073K for 3.0s (OM)



α：ferrite γ(M)：martensite transformed from austenite θ：cementite

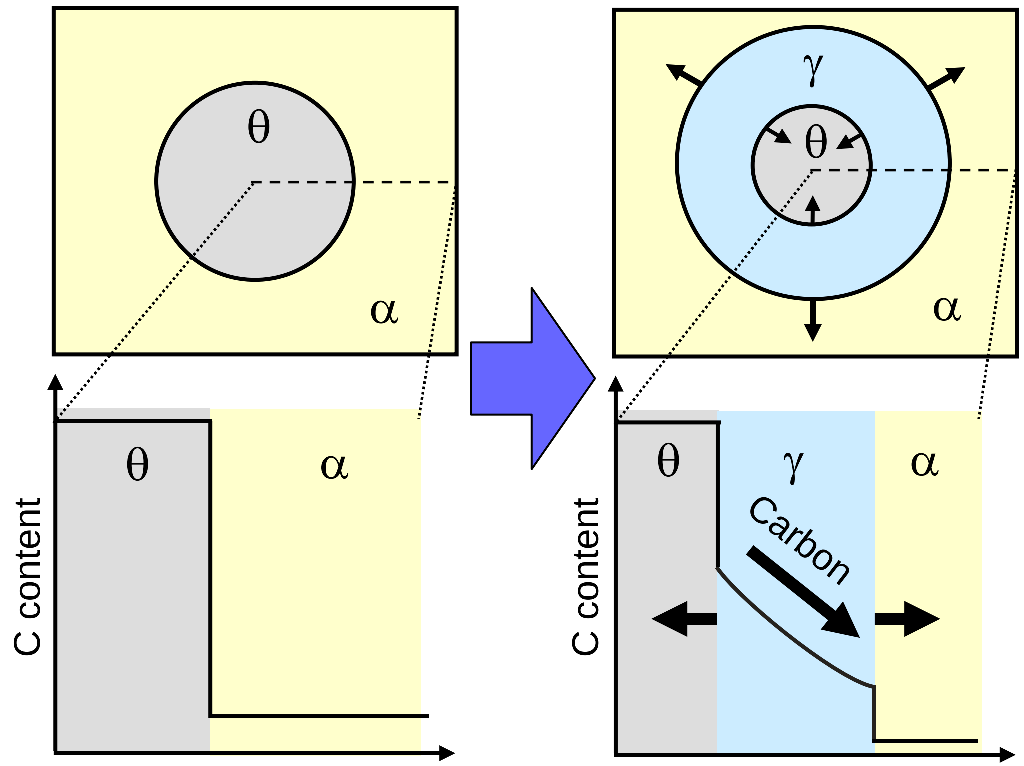
Variations in volume fraction of transformed region and θ



- Reverse transformation kinetics of 0.6C alloy is the fastest.
- Adding alloying element delays reverse transformation.
- Reverse transformation kinetics of 1Cr alloy is extremely slow.

The model of γ growth

M. Hillert et al. : J. Iron Steel Inst., 209(1971), 49.



<u>Assumptions</u>

- γ nucleates at α / θ interface and envelopes θ.
- Local equilibrium is established at phase boundaries.
- Diffusion in α is ignored.

In Fe-C binary system, γ growth is controlled by carbon diffusion in γ.

Alloying element(M) would affect carbon diffusion in Fe-C-M alloy

Partitioning of M between α and θ after tempering analyzed by ICP

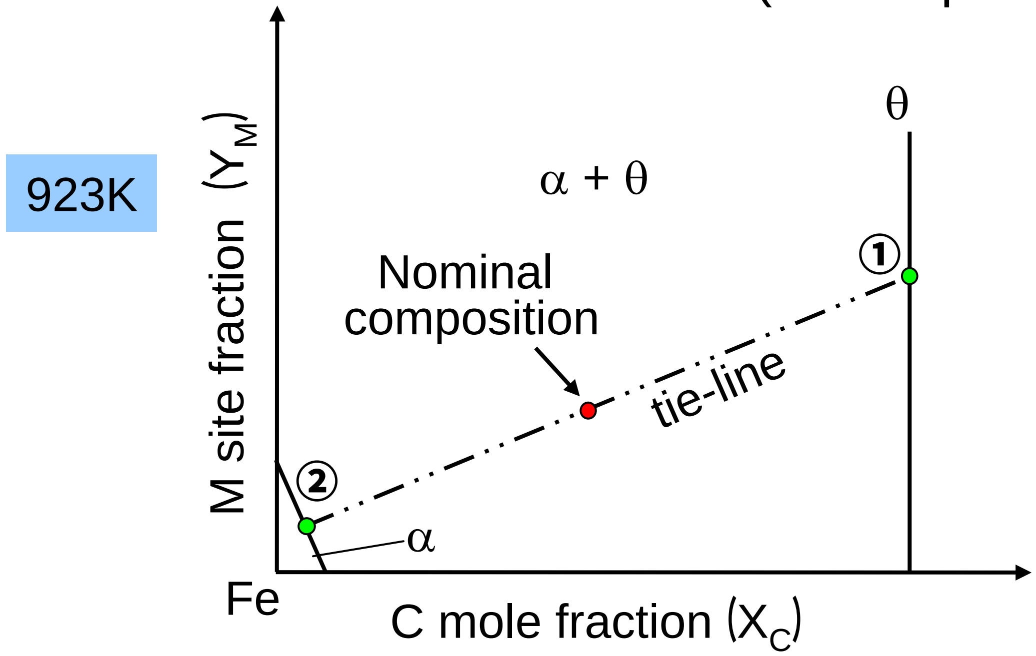
	1Mn	1Si	1Cr
Y_M^{θ}	<u>0.072</u>	0.00	<u>0.112</u>
Y_M^{α}	0.005	<u>0.022</u>	0.001

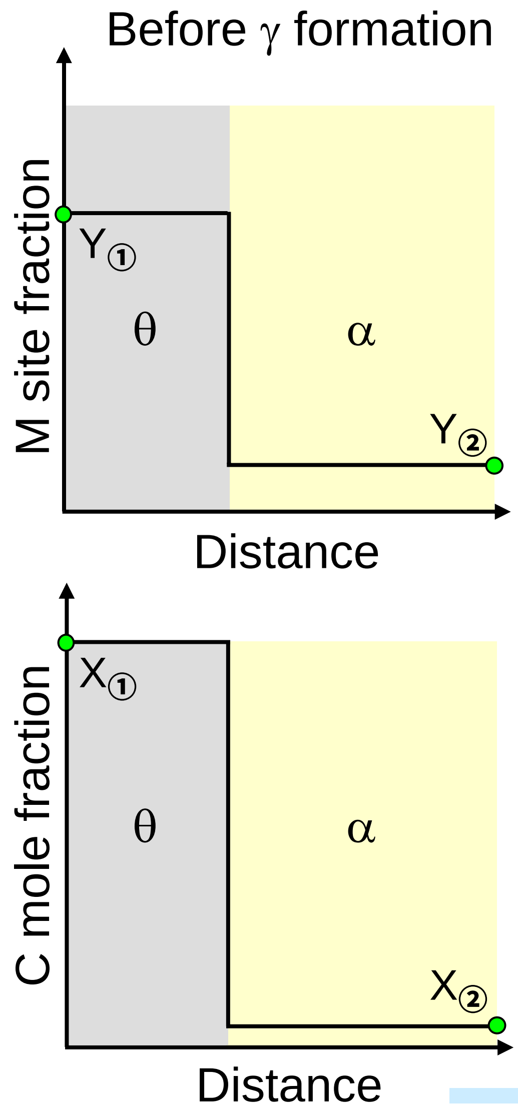
Y_i^j : Site fraction of *i* in *j*-phase

$$Y_i^j = \frac{X_i^j}{1 - X_C^j}$$

Effect of alloying elements on γ growth

● Before reverse transformation (As-tempered), 923K

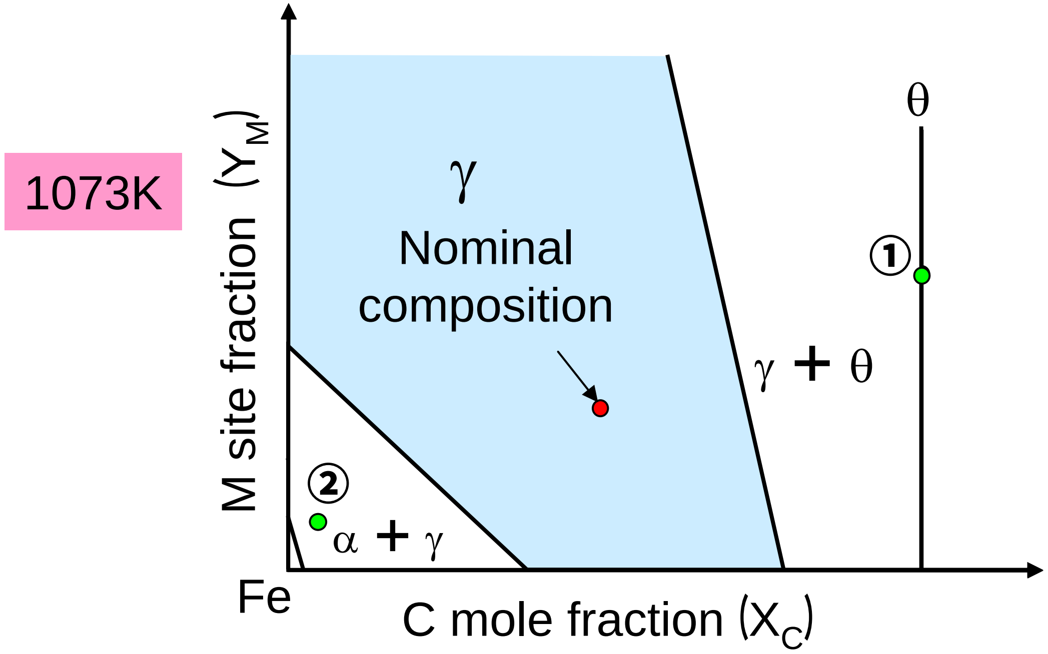


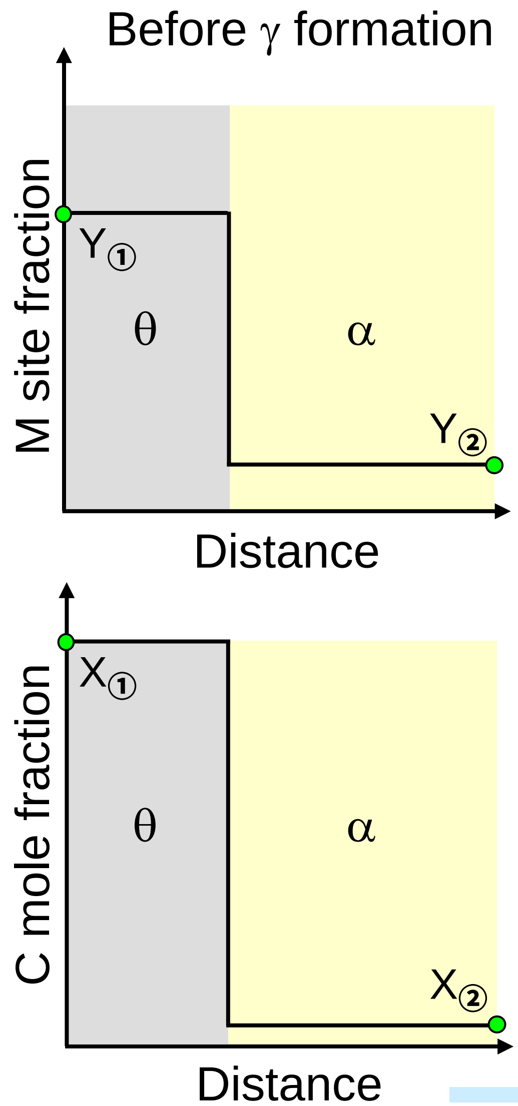


Alloying element redistributes between α and θ by tempering at 923K before reverse transformation.

Effect of alloying elements on γ growth

● Reverse transformation at 1073K

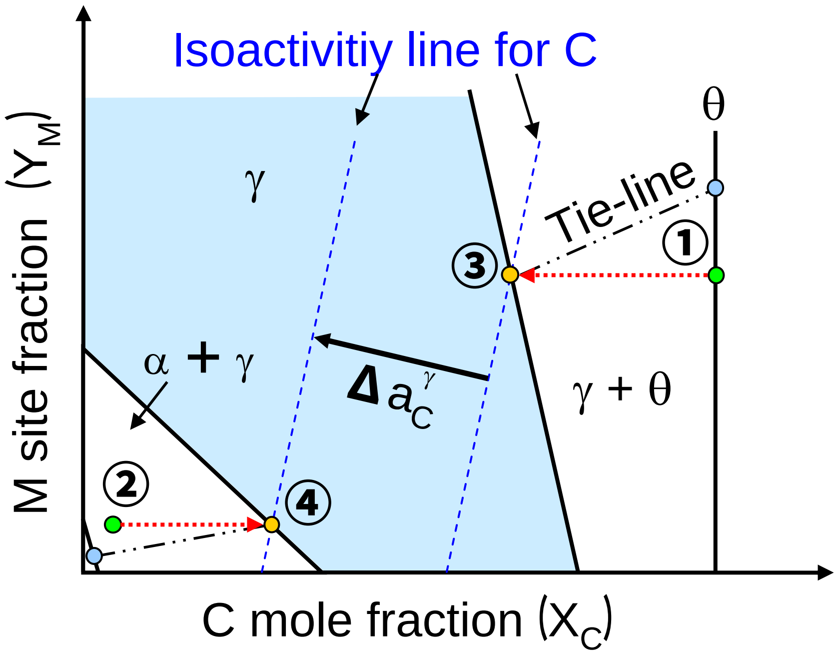




Alloying element redistributes between α and θ by tempering at 923K before reverse transformation.

Effect of alloying elements on γ growth

●It is assumed that γ grows without long range diffusion of alloying element

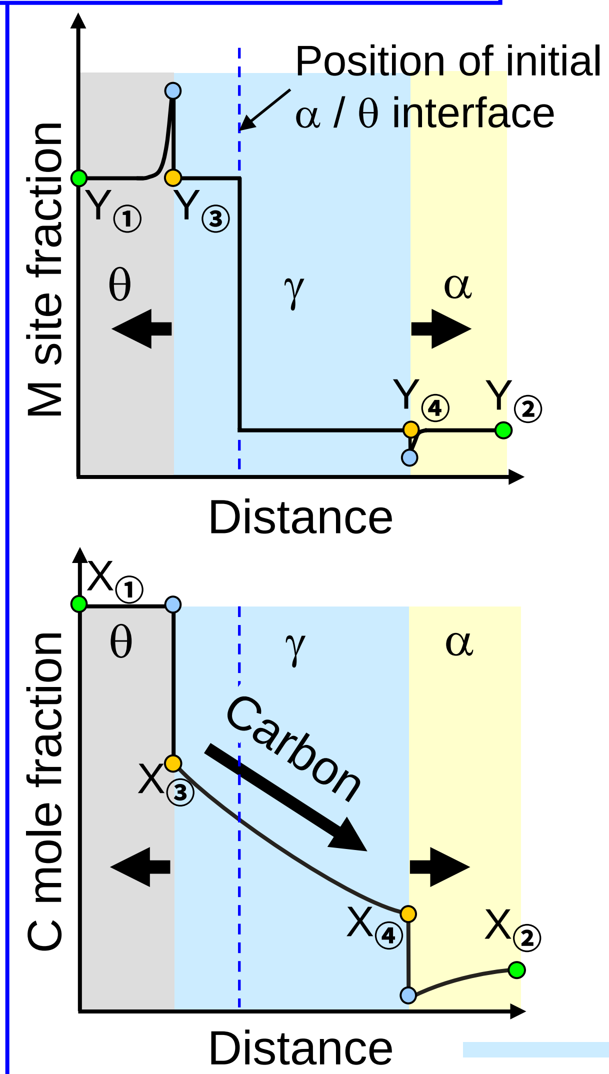


For the partitionless γ growth, C activity at ③($a_C^{③}$) should be higher than C activity at ④($a_C^{④}$) .

$a_C^{③} > a_C^{④}$ ➡ γ can grow without long range diffusion of alloying element.

$a_C^{③} < a_C^{④}$ ➡ Long range diffusion of alloying element is necessary for γ growth.

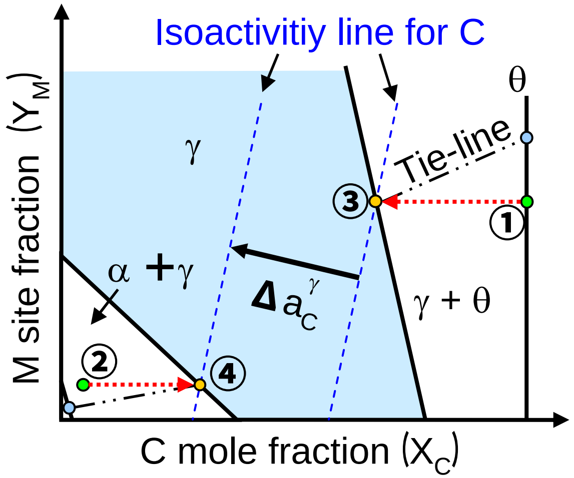
In the case of $a_C^{③} > a_C^{④}$



Thermodynamic analysis by Thermo-Calc

Carbon activity difference in γ

	0.6C	1Mn	1Si	1Cr
$\Delta \ln a_C = \ln a_C$ ③ - $\ln a_C$ ④	1.28	1.09	0.60	-2.57



0.6C, 1Mn and 1Si alloys

γ can grow without long range diffusion of alloying element.

Rate controlling process is carbon diffusion in γ.

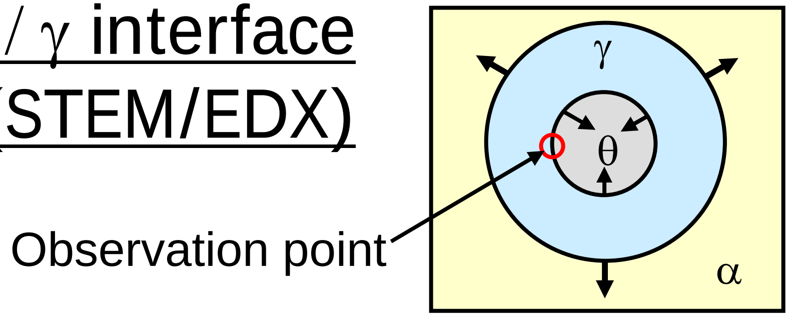
By adding alloying element, the difference of carbon activity in γ decreases. This leads to lower γ growth rate.

1Cr alloy

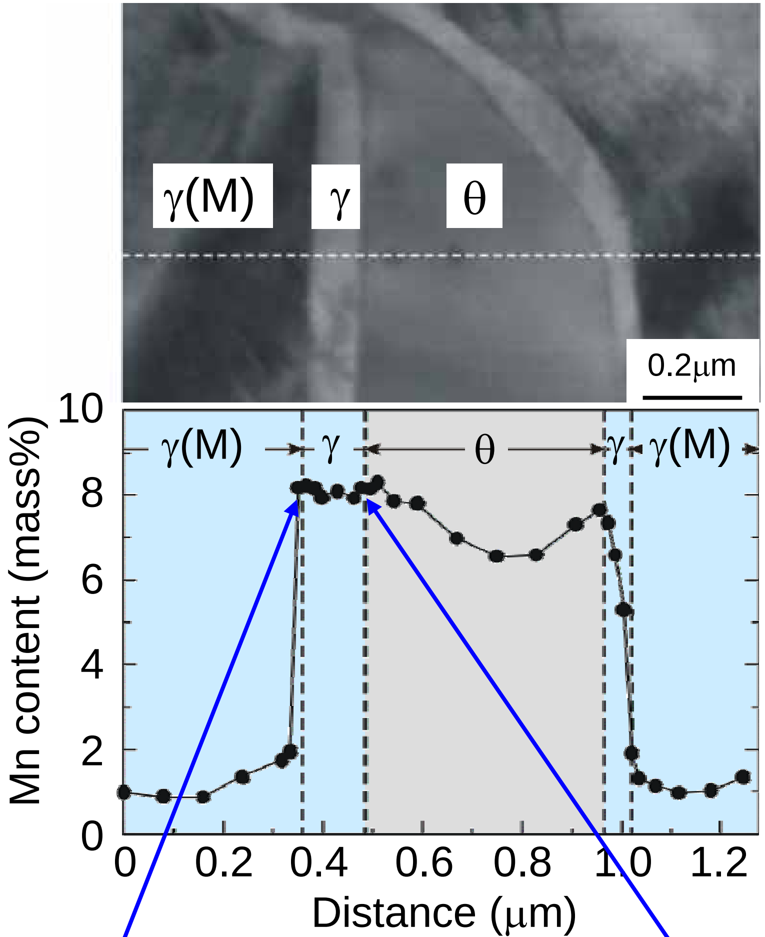
Long range diffusion of Cr is necessary for γ growth.

Rate controlling process is Cr diffusion in γ.

Partitioning of alloying element at θ / γ interface (STEM/EDX)

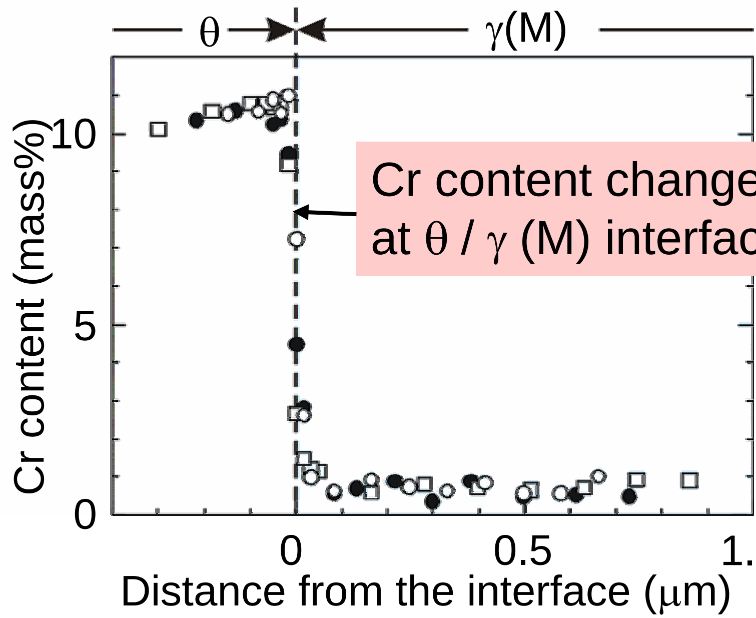


1Mn alloy transformed at 1073K for 3.0s

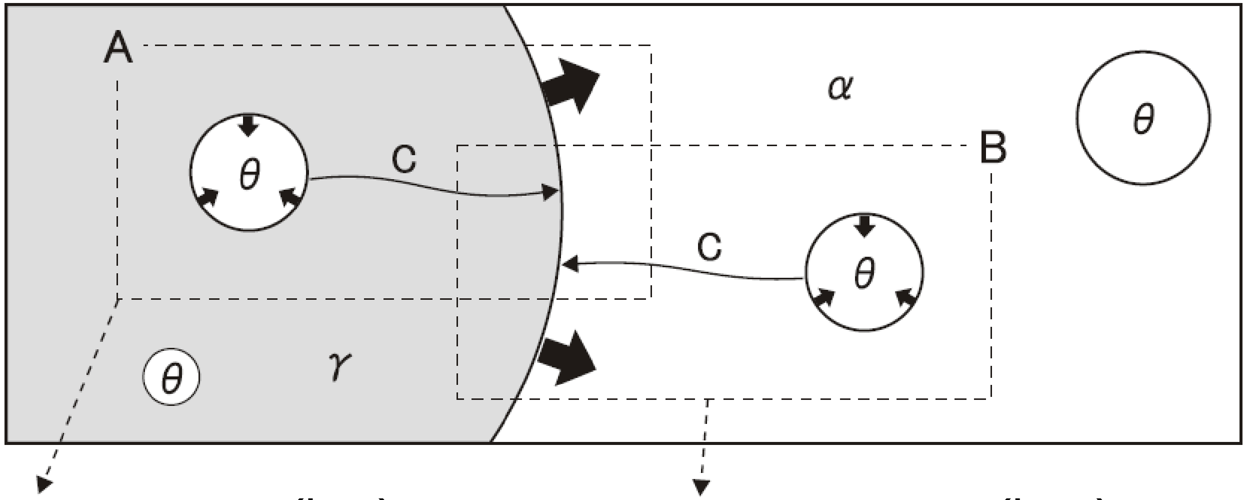


Mn content is constant at retained γ / θ interface while it changes significantly at γ (M) / retained γ interface.

1Cr alloy transformed at 1073K for 60s



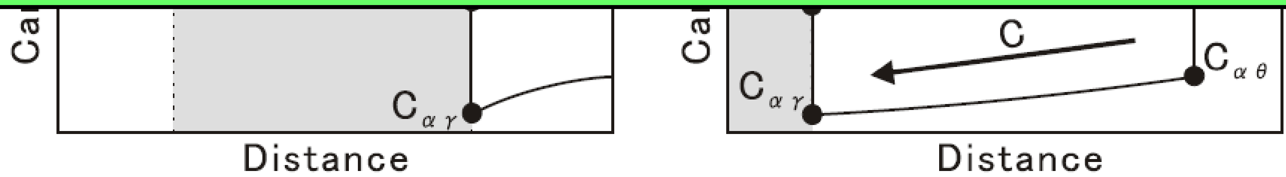
In 1Mn alloy, θ / γ interface moves without Mn partitioning while in 1Cr alloy, it moves with Cr partitioning.



Type A (in γ)　　　Type B (in α)

$\Delta \ln(a_C)$ estimated from phase diagram

	Type A		Type B	
	NPLE	PE	NPLE	PE
0.6C	1.28	1.28	1.17	1.17
1Mn	1.09	1.34	0.52	1.08
1Si	0.60	0.70	0.49	0.60
1Cr	-2.57	0.28	-2.54	0.11



Conclusions

Alloying effects of Mn, Si, Cr on reverse transformation kinetics from tempered martensite to γ was investigated.

- Reverse transformation kinetics of 0.6C binary alloy is the fastest and becomes slower by the addition of these alloying elements. Among ternary alloys, reverse transformation kinetics of 1Cr alloy is extremely slow.

- In 1Mn and 1Si alloys, γ grows without partitioning of alloying element. Decrease in carbon activity in γ by the addition of these elements may result in slower reversion kinetics.

- In 1Cr alloy, γ grows accompanying with Cr partitioning, resulting in extremely slow reversion kinetics.