

ALEMI 13th workshop

May 26 & 27, 2014, Kansai Seminar House, Kyoto

Effects of C, Si and Mn Contents on
Mechanical Property
in Medium-Manganese Steel Sheets

May 27, 2014

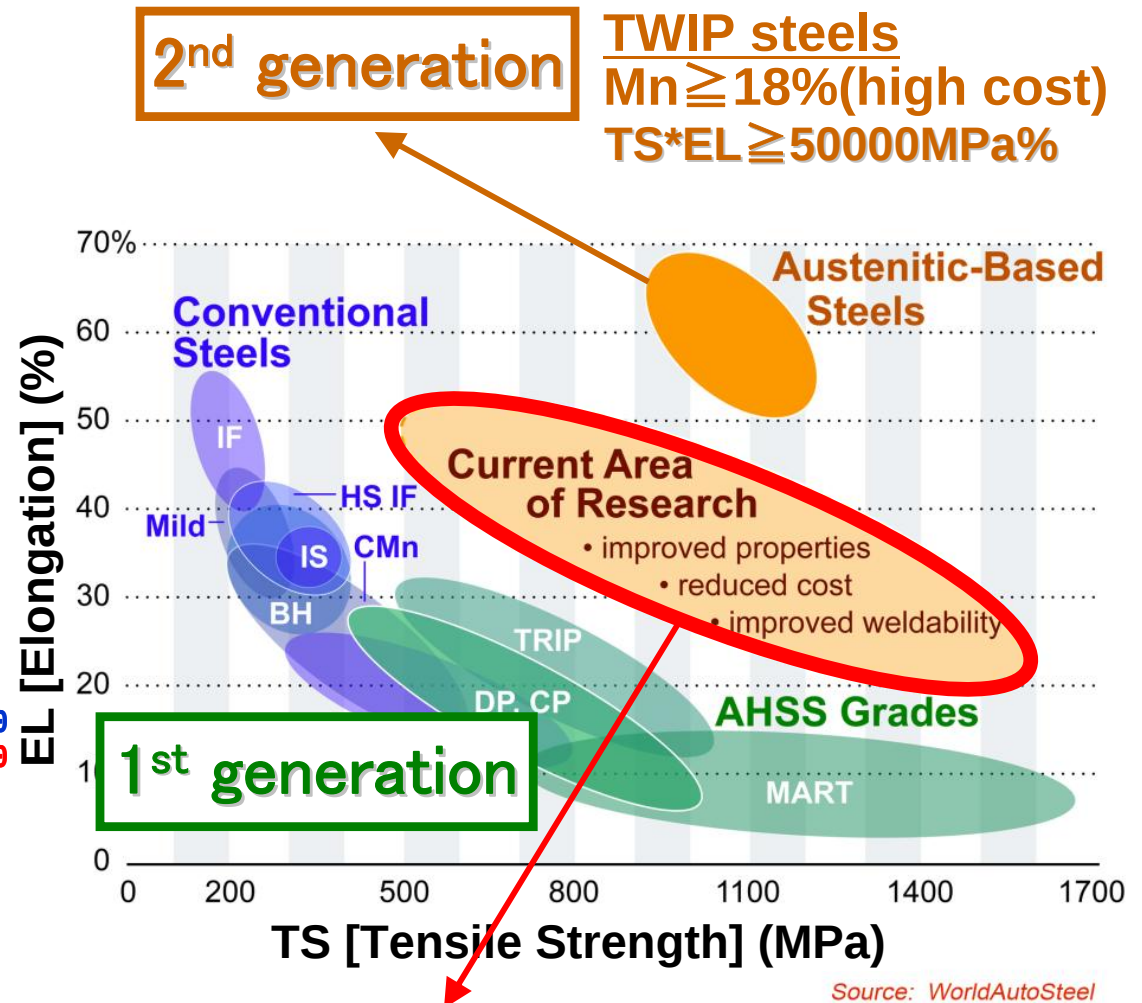
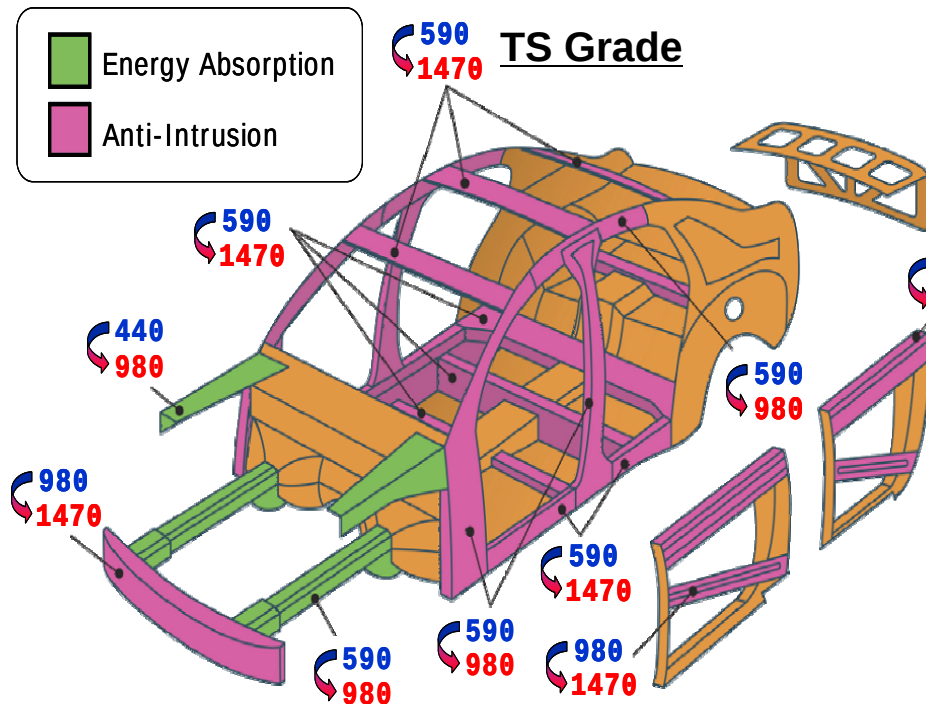
Y. Kawasaki, T. Yamashita, H. Matsuda, K Okuda, T. Yokota

Steel Research Laboratory, JFE Steel Corporation, Japan

3rd Generation AHSS (Advanced High Strength Steel)

Various AHSS have been developed

- ◆ to reduce weight of the car body
- ◆ to improve the passenger safety



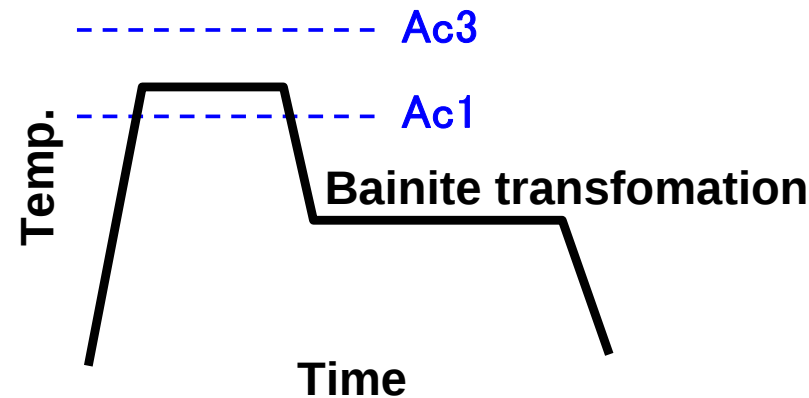
3rd generation

e.g. Medium Mn-TRIP steels
4~8wt%Mn
TS*EL $\geq$ 30000MPa%

Comparison of Conventional TRIP Steels and Medium Mn-TRIP Steels

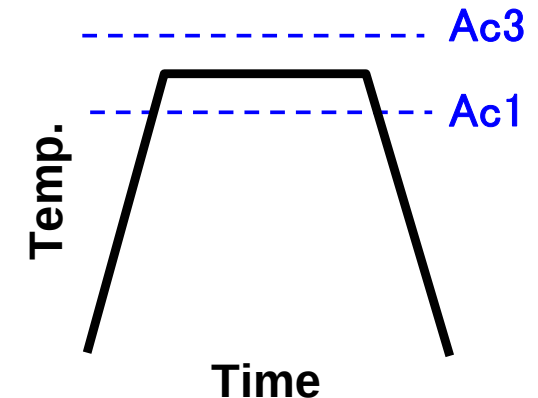
Conventional TRIP steels

- To Contain **Si** to prevent carbide formation
- To Obtain retained austenite at the end of bainite transformation accumulates **C** concentration



Medium Mn-TRIP steels (4~8wt%Mn)

Stability of austenite can be attributed to partitioning of **Mn** between ferrite and austenite during intercritical annealing^[1-4]

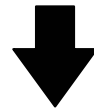


[1] R.L. Miller: *Metallurgical Transactions*, Vol. 3 (1972), p.905.

[2] T. Furukawa: *Materials Science and Technology*, Vol. 5 (1989), p.465.

[3] H. Huang, O. Matsumura, T. Furukawa: *Materials Science and Technology*, Vol. 10 (1994), p.621.

[4] T. Furukawa, H. Huang, O. Matsumura: *Materials Science and Technology*, Vol. 10 (1994), p.964.



Influences of Mn, C and Si contents on mechanical property and microstructure in medium Mn-TRIP steels have not been discussed in detail.

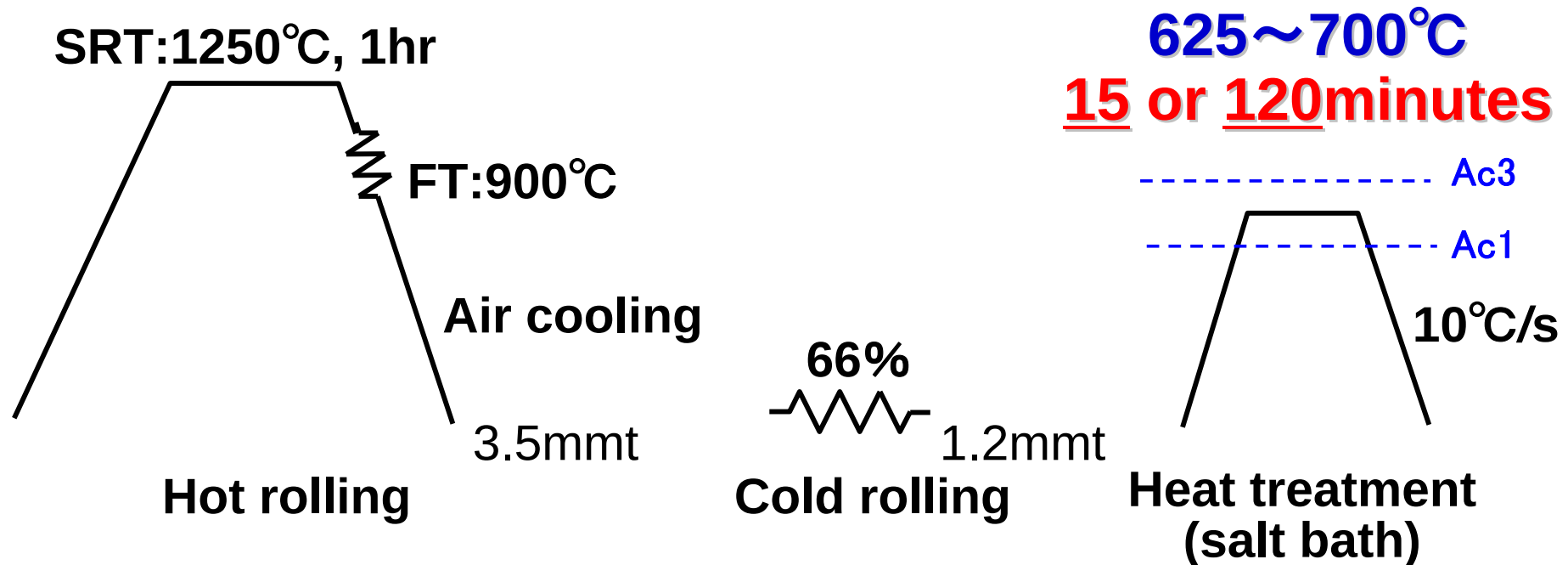
To investigate effects of Mn, C and Si contents on mechanical property and microstructure in Medium Mn-TRIP steels

【Chemical compositions】

Steel	C	Si	Mn	Note (wt%)
A	0.156	1.49	6.55	0.15C-1.5Si-6.5Mn
B	0.010	1.50	6.56	<u>0.01C</u> -1.5Si-6.5Mn
C	0.072	1.49	6.58	<u>0.07C</u> -1.5Si-6.5Mn
D	0.270	1.51	6.51	<u>0.25C</u> -1.5Si-6.5Mn
E	0.149	0.02	6.59	0.15C- <u>0.02Si</u> -6.5Mn
F	0.149	0.50	6.55	0.15C- <u>0.5Si</u> -6.5Mn
G	0.143	1.01	6.53	0.15C- <u>1.0Si</u> -6.5Mn
H	0.152	1.53	3.51	0.15C-1.5Si- <u>3.5Mn</u>
I	0.148	1.47	4.52	0.15C-1.5Si- <u>4.5Mn</u>
J	0.145	1.60	5.42	0.15C-1.5Si- <u>5.5Mn</u>
K	0.145	1.40	8.06	0.15C-1.5Si- <u>8.0Mn</u>

C(0.01-0.25), Si(0.02-1.5) and Mn(3.5-8.0) contents were changed.

【Processing conditions】



【Testing procedures】

- ◆ Tensile test (JIS No. 5, Rolling direction, 10mm/min.)
- ◆ Volume fraction of retained austenite: X-ray (Mo-K α)
- ◆ Microstructure observation: FE-EPMA and FE-SEM/EBSD

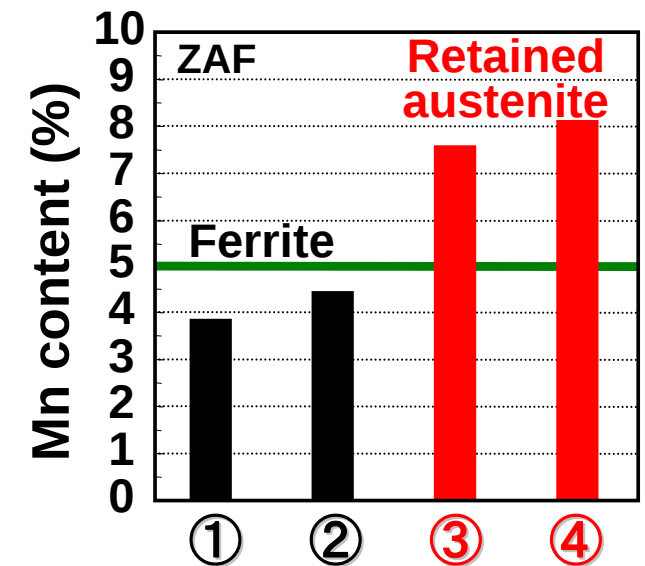
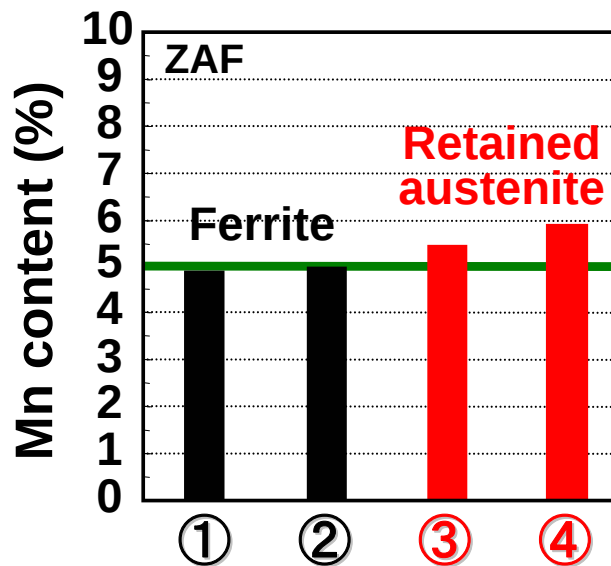
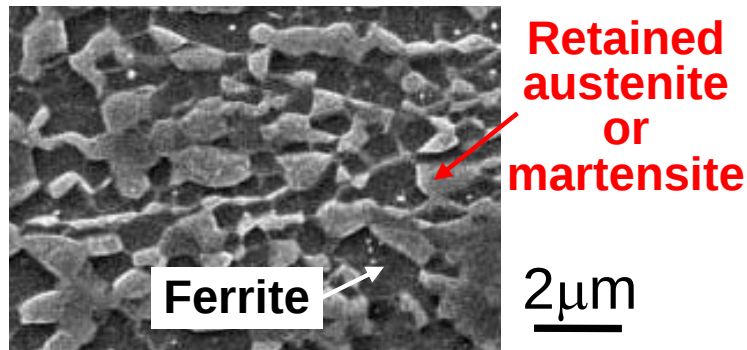
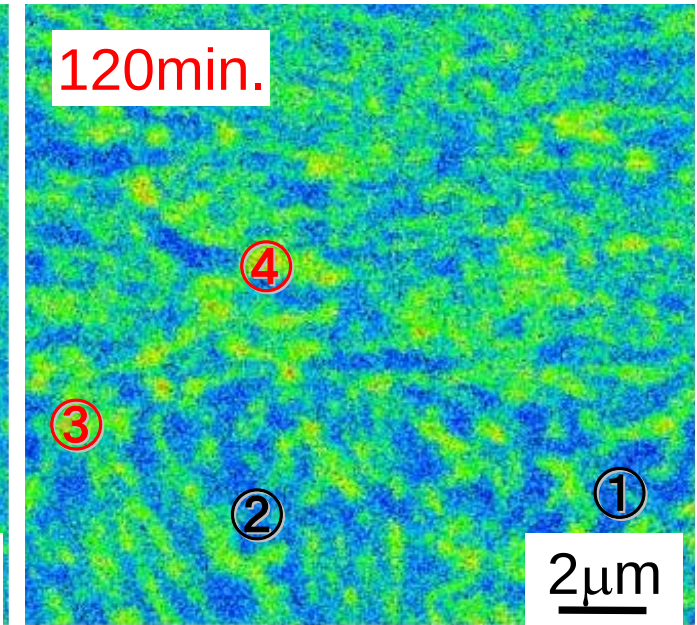
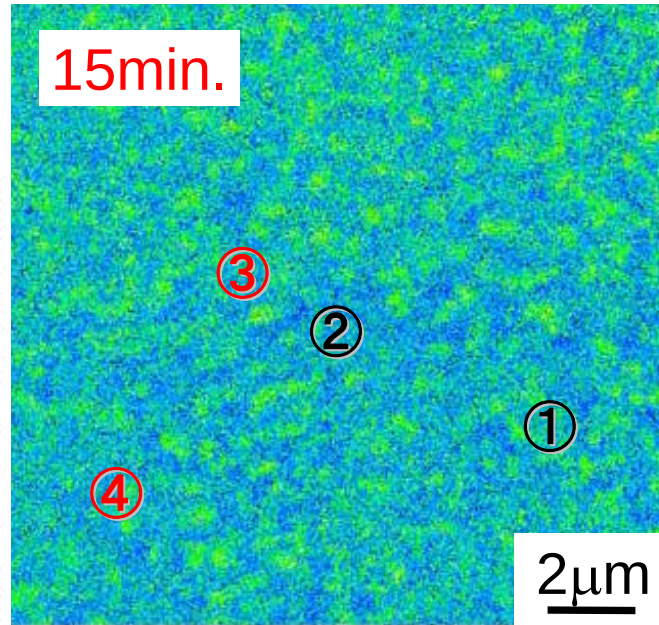
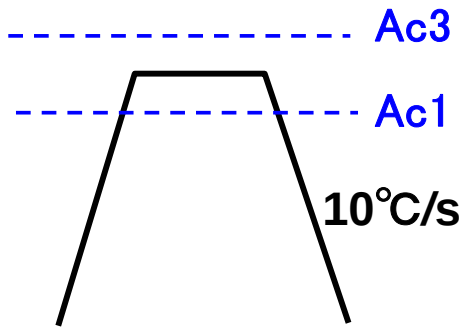
Effect of Annealing Time on Retained Austenite

e.g. 5%Mn steels

EPMA analysis

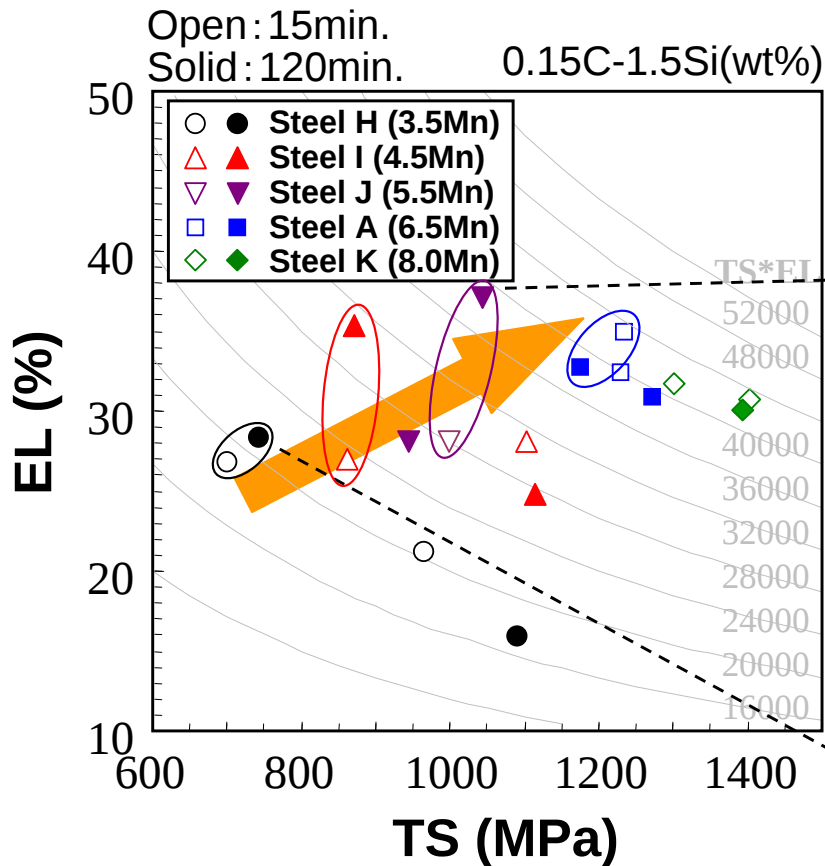
Mn Map

650°C
15 or 120min.

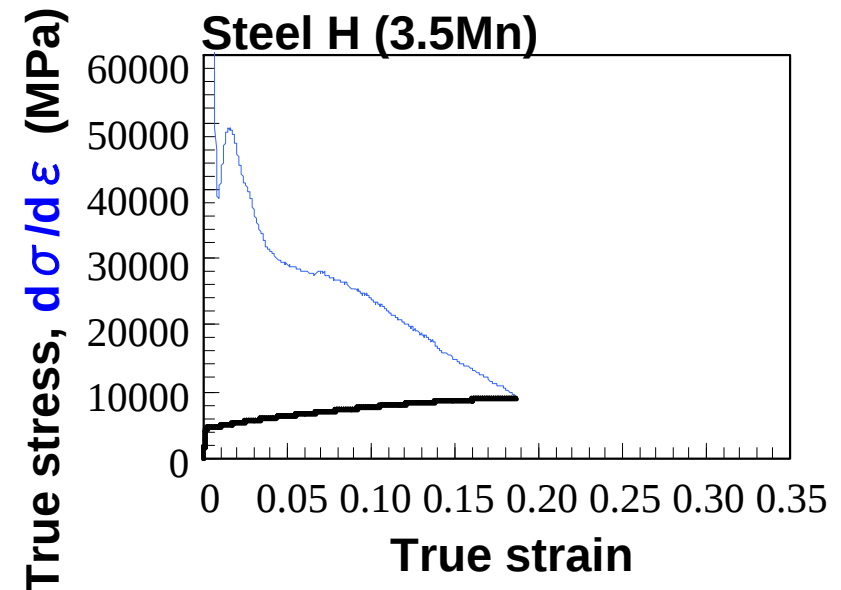
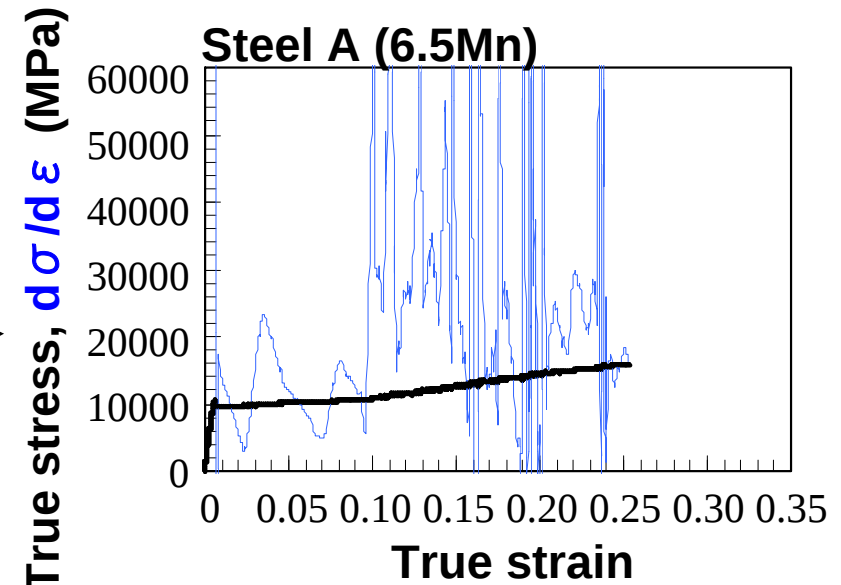


Mn concentration of austenite during intercritical annealing

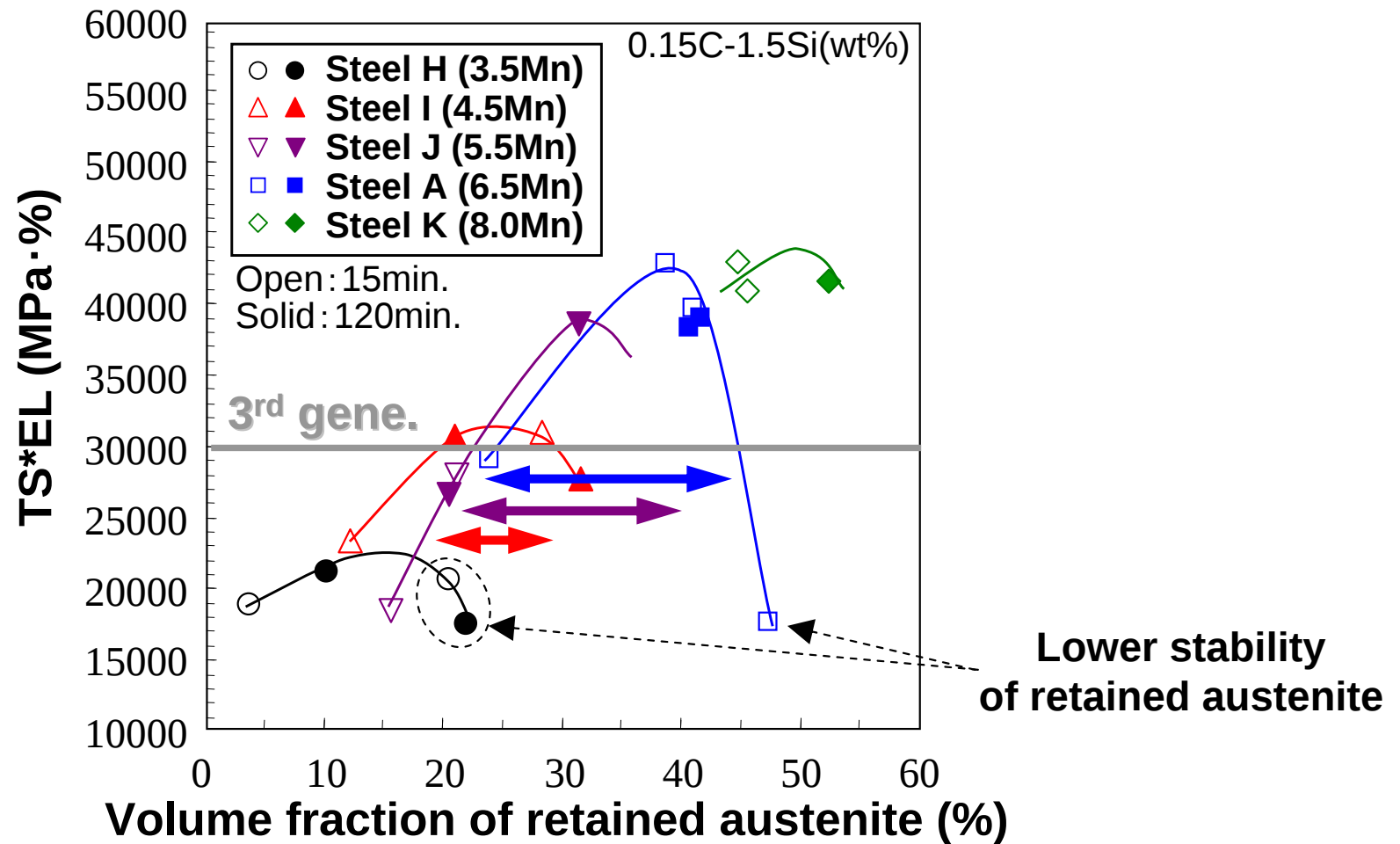
Effect of **Mn** Content on Mechanical Property



TS-EL balance of the champion data were improved with increase in Mn content from 3.5 to 6.5wt%.

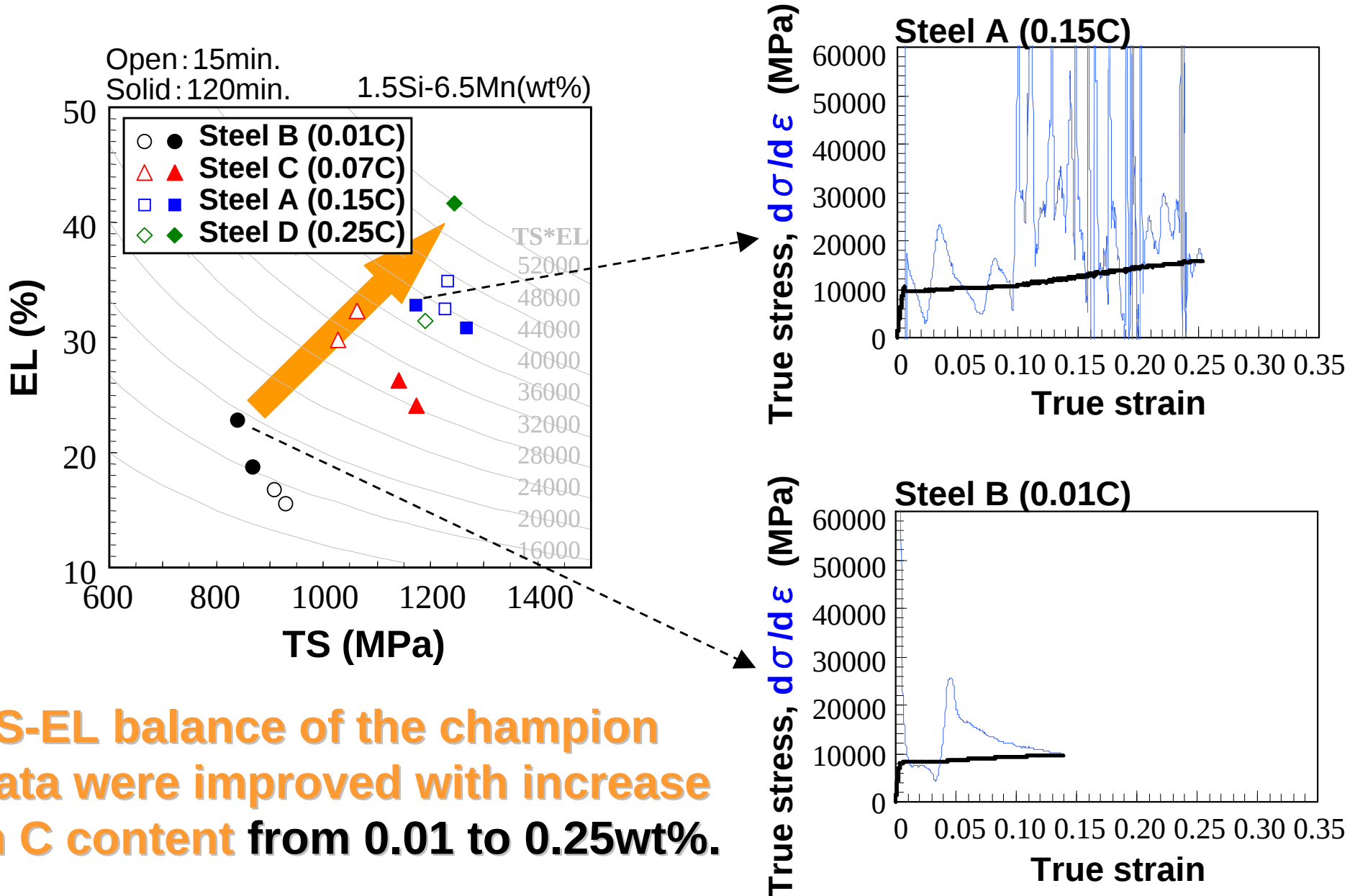


Effect of **Mn** Content, Volume Fraction of Retained Austenite on TS-EL Balance

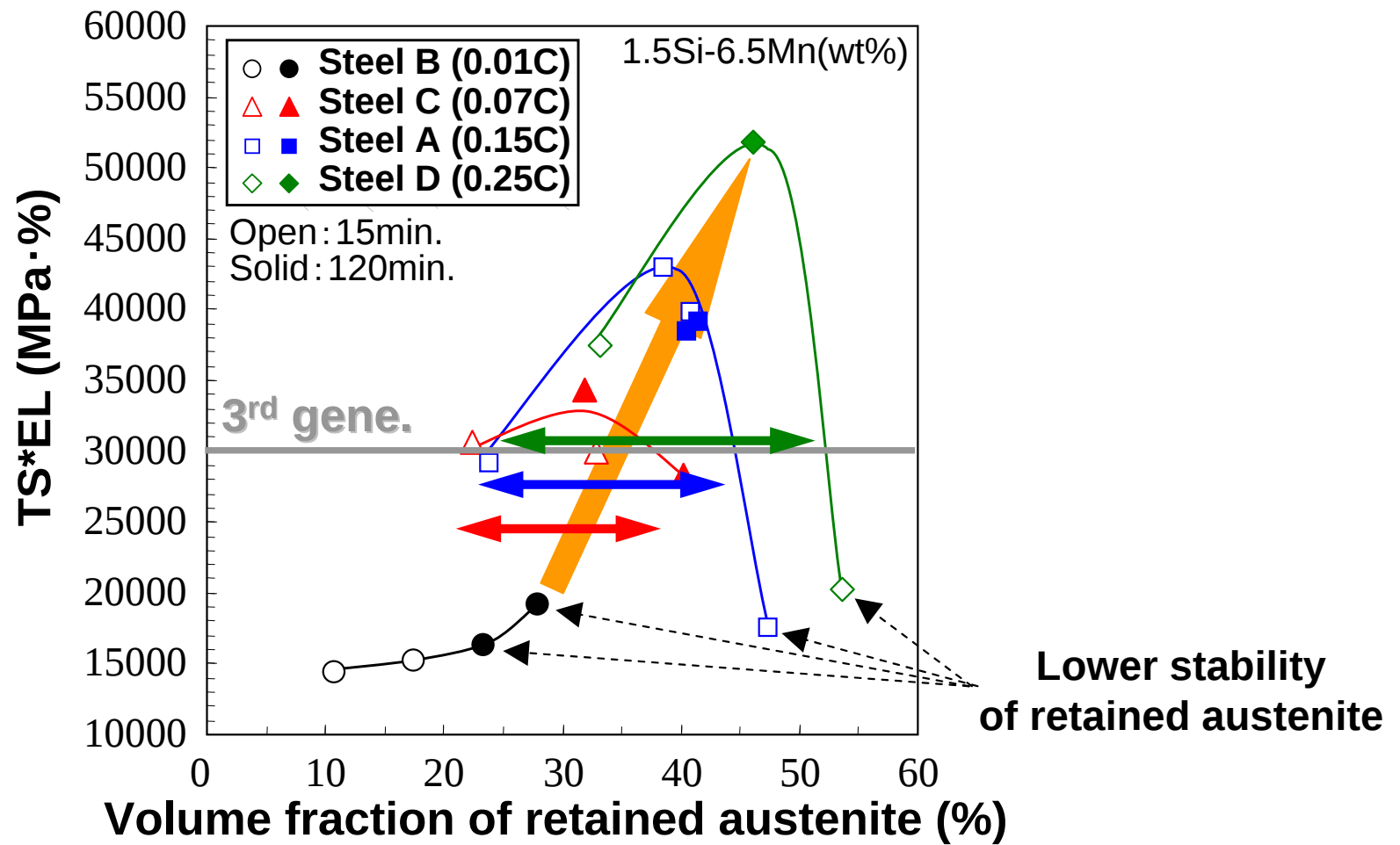


Steels with more than 4.5wt%Mn achieved performance of 3rd generation, when volume fraction of retained austenite were controlled in optimum range.

Effect of **C** Content on Mechanical Property

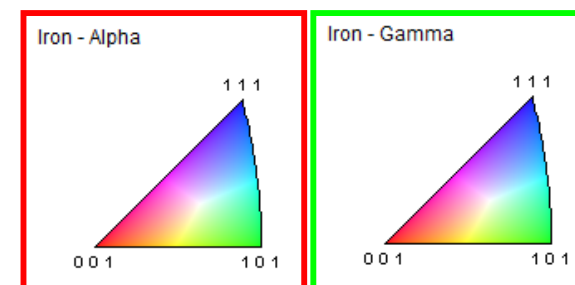
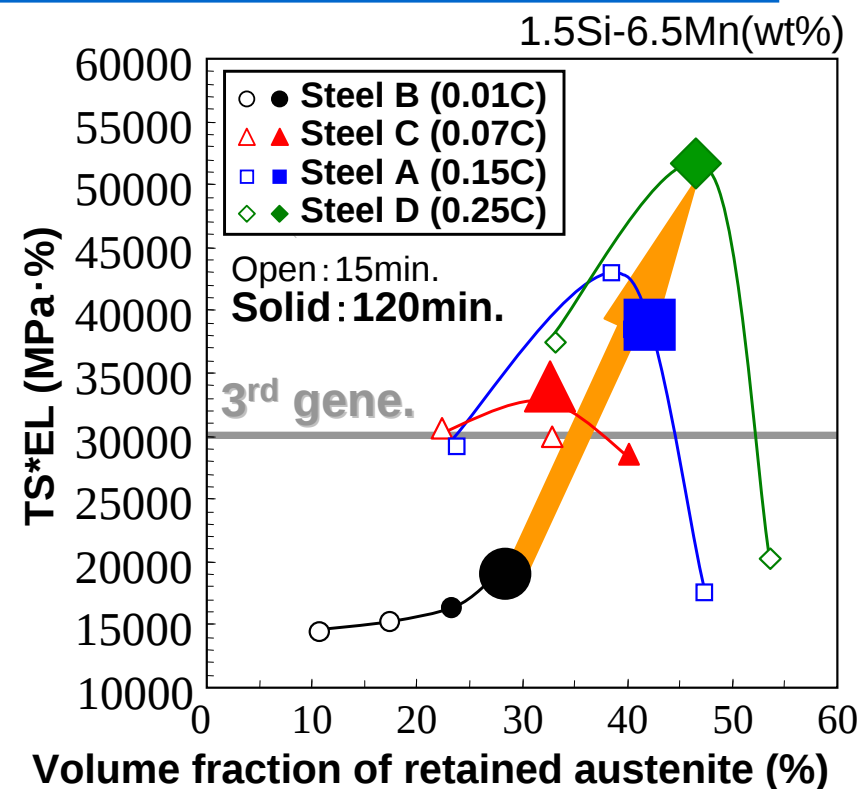
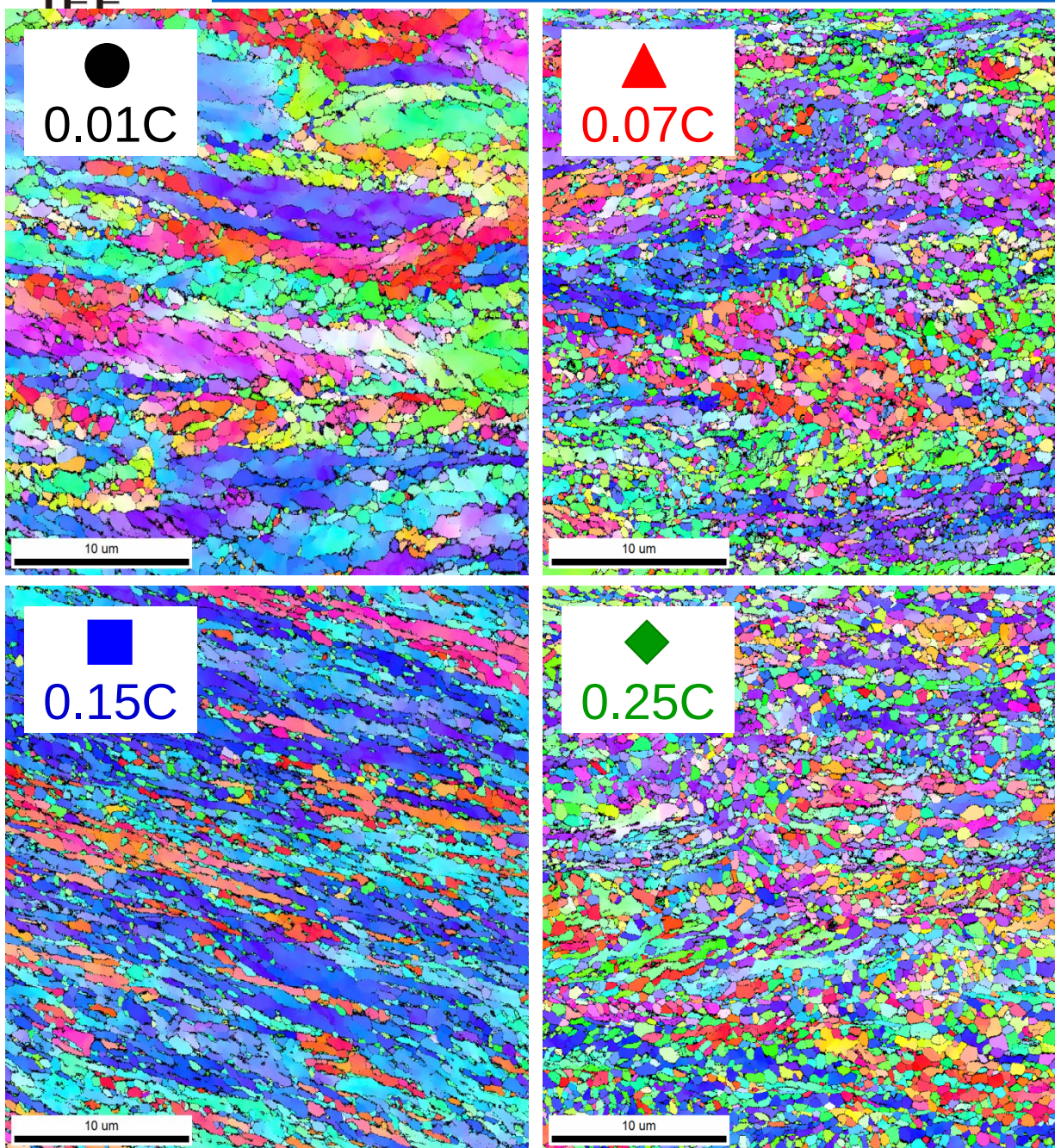


Effect of **C** Content, Volume Fraction of Retained Austenite on TS-EL Balance



Steels with more than 0.07wt%C achieved performance of 3rd generation, when volume fraction of retained austenite were controlled in optimum range.

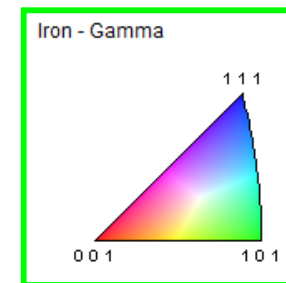
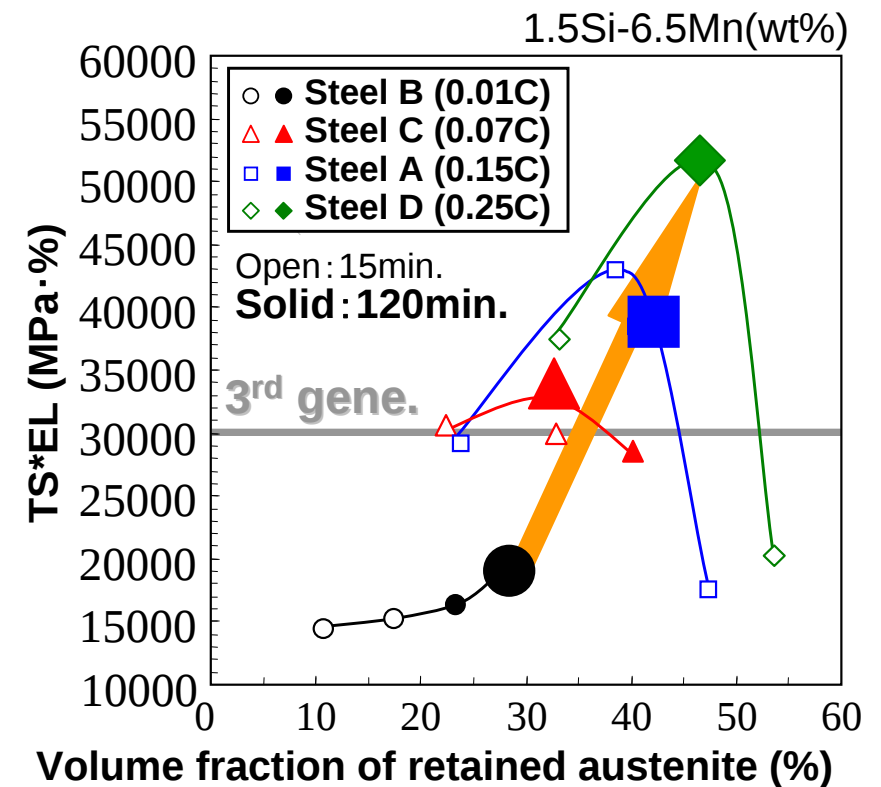
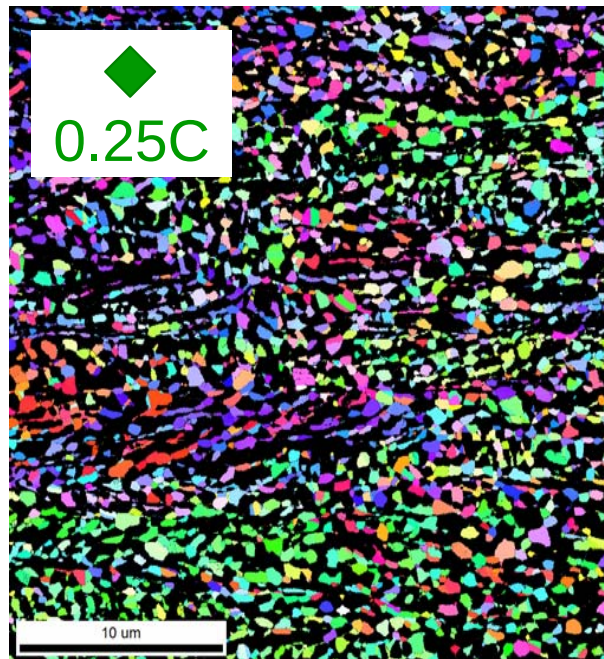
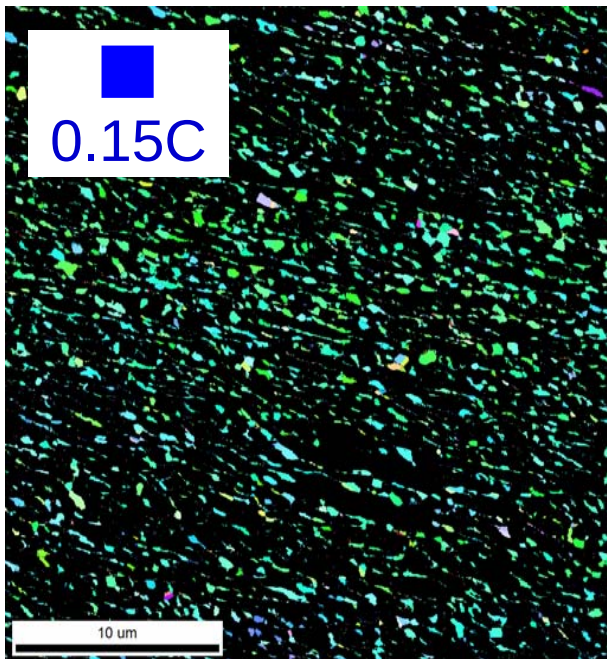
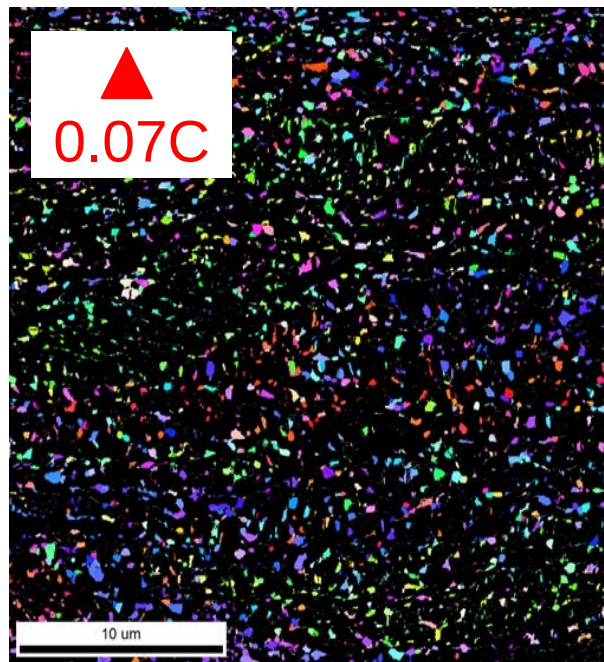
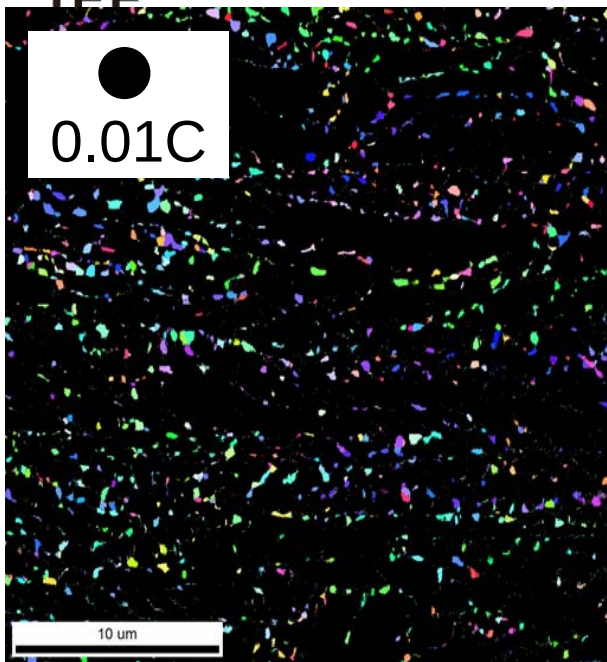
FE-SEM/EBSD Analysis - IPF Map : BCC & FCC



Fine structure

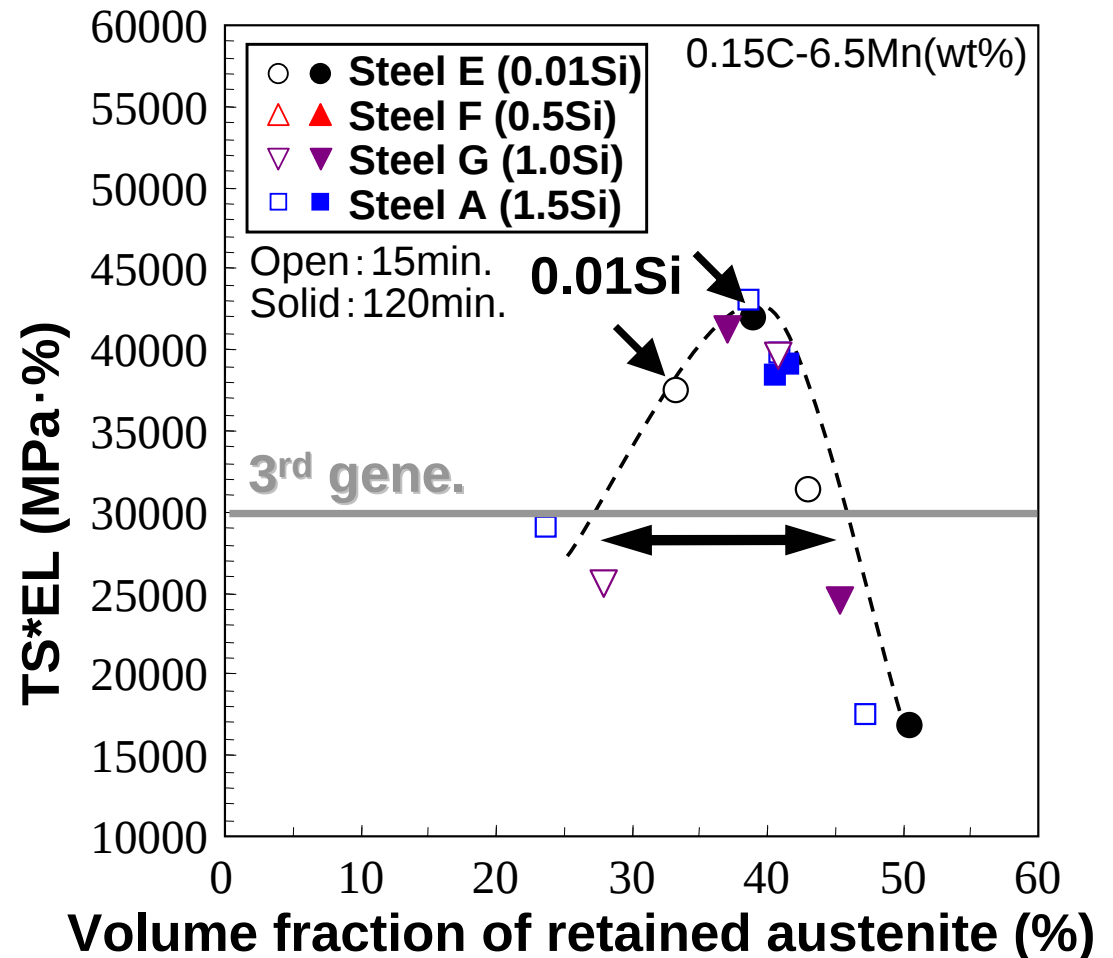
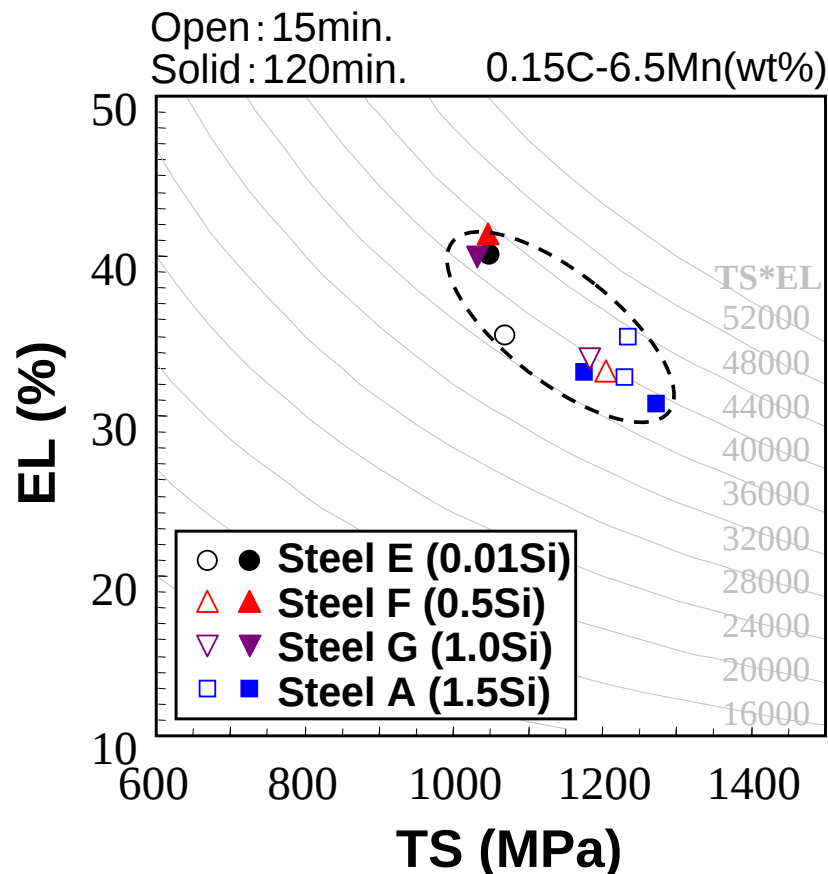


FE-SEM/EBSD Analysis - IPF Map : FCC



Increase in volume fraction of retained austenite
→ **Increase in TS-EL balance**

Effect of **Si** Content, Volume Fraction of Retained Austenite on TS-EL Balance



Effect of Si content on TS-EL balance was very small.

Regardless of Si content, Optimum range of volume fraction of retained austenite was from 25 to 45%.

Conventional TRIP steels need Si addition to prevent carbide formation.

Medium Mn-TRIP steels

	Mn	C	Si
TS*EL	Increase	Increase	No change
Main reason	Increase in stability of retained austenite	Increase in volume fraction of retained austenite	-

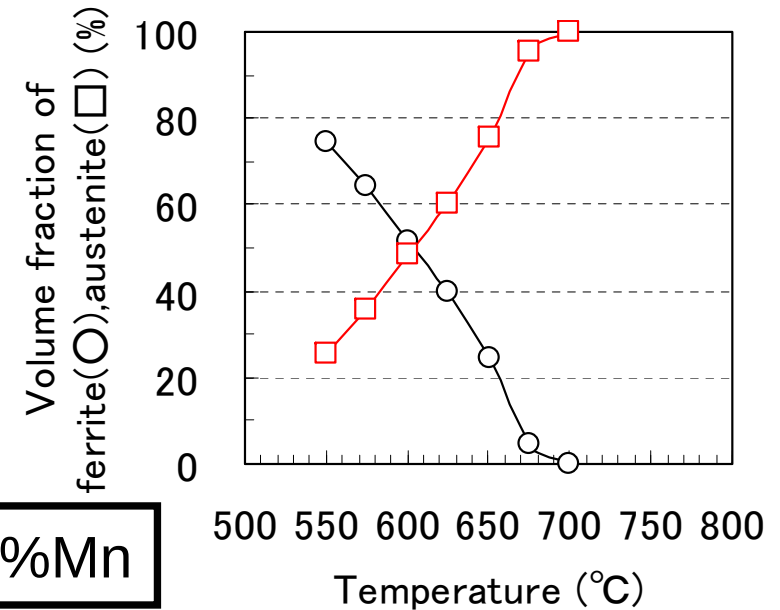
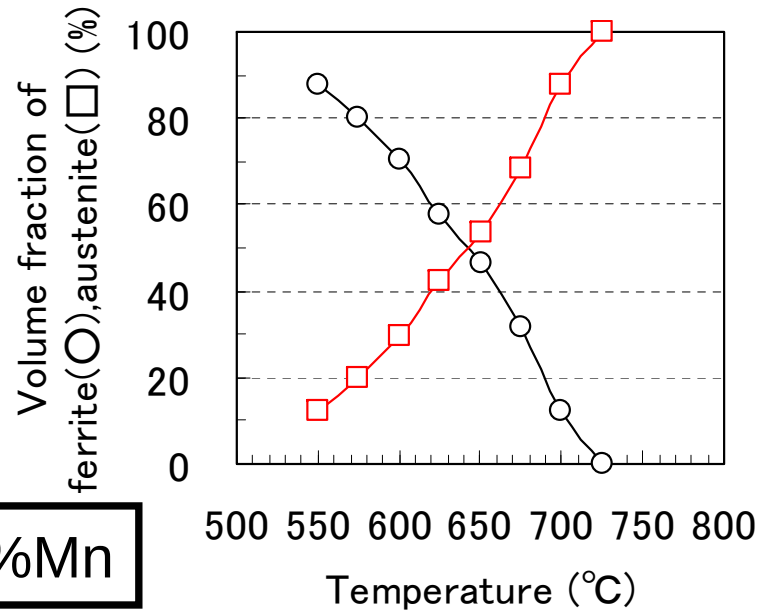
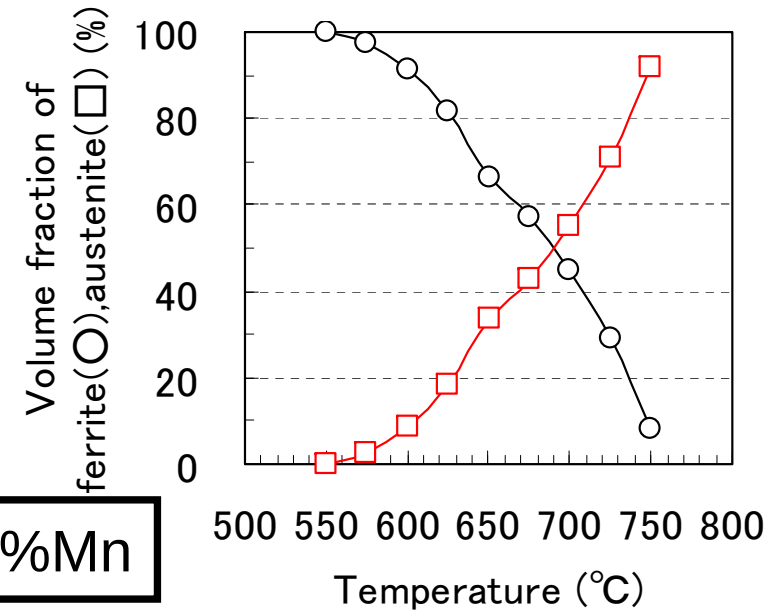
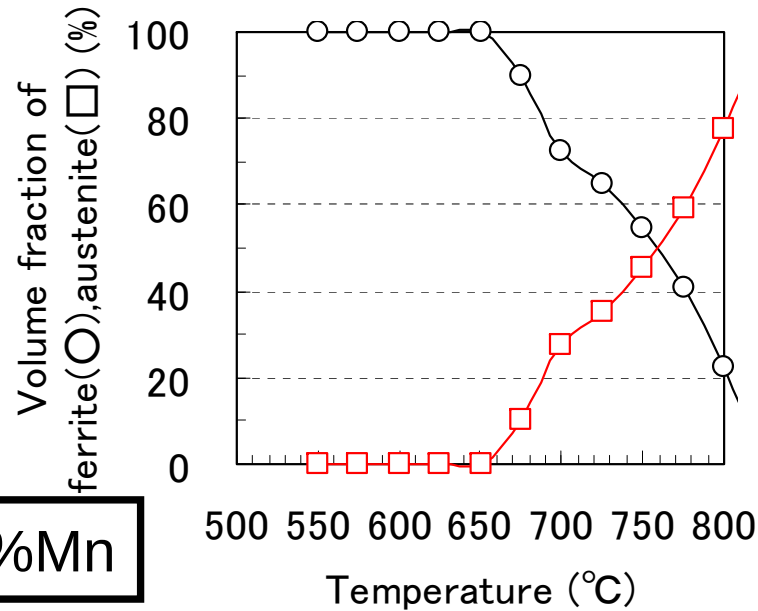
- 1) TS-EL balance of the champion data were improved with increase in Mn and C contents in medium-Mn TRIP steels. On the other hand, effect of Si content on TS-EL balance was very small.
- 2) Increase in Mn and C contents led to increase in $d\sigma/d\varepsilon$ (work - hardening rate) in the high strain region. In addition, $d\sigma/d\varepsilon$ of local strain were increased remarkably and showed unique behavior.
- 3) Optimum range of volume fraction of retained austenite existed to obtain higher TS-EL balance.

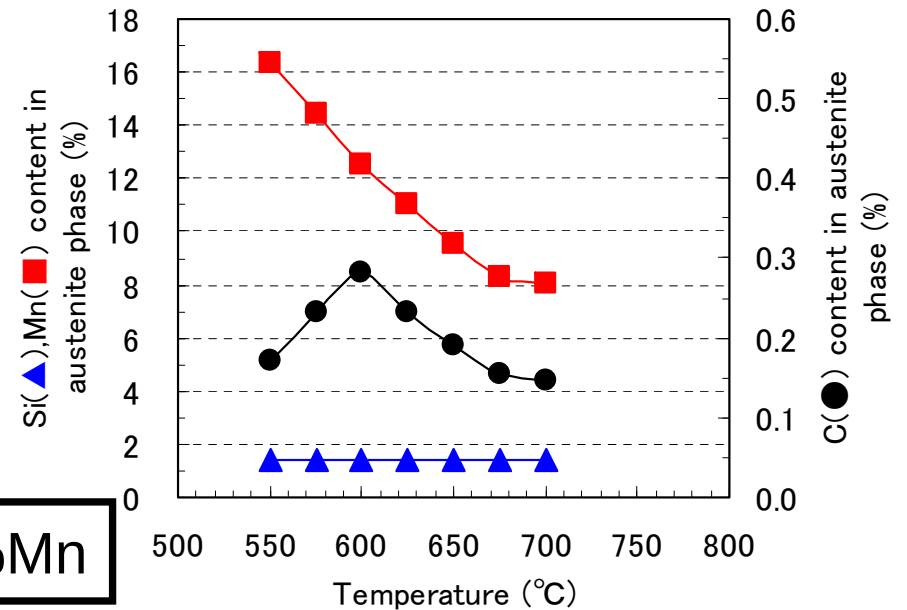
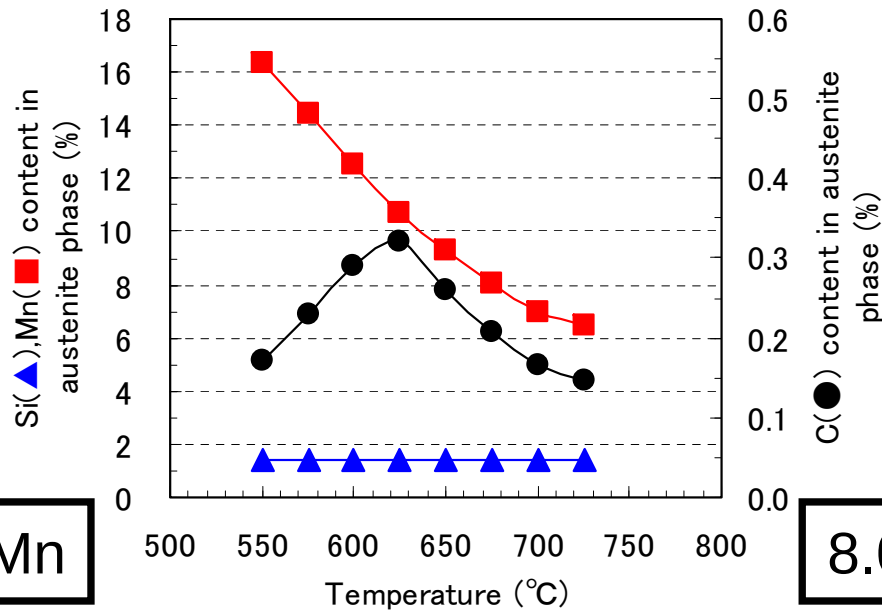
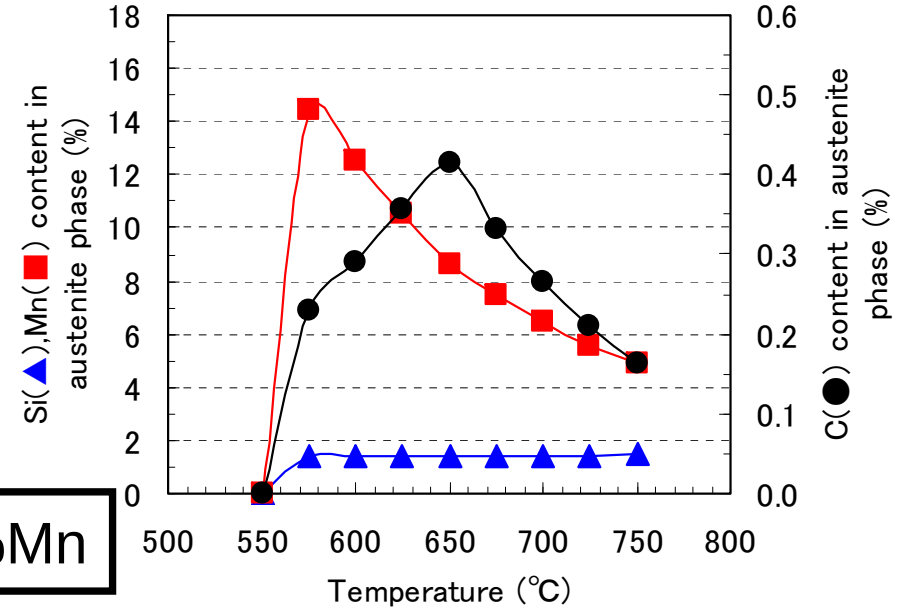
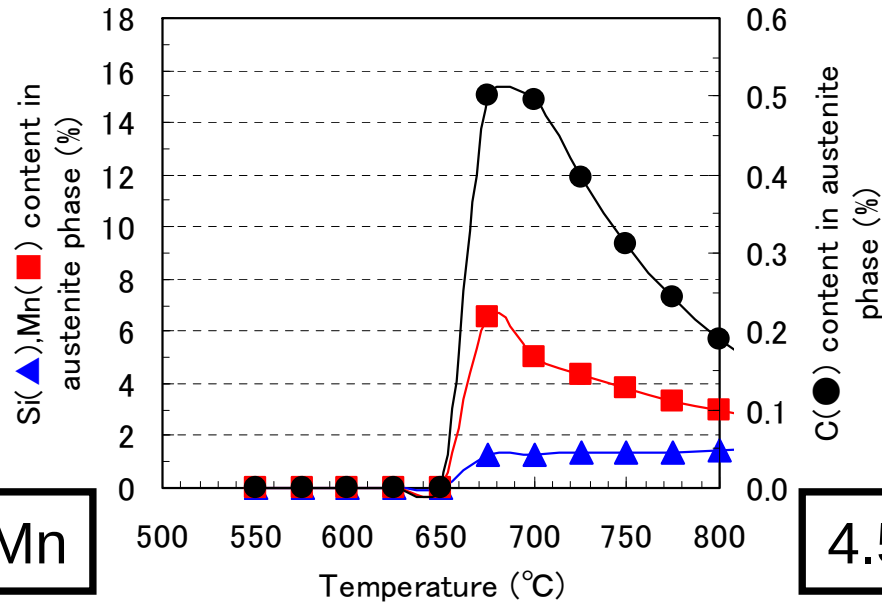
Thank you for your kind attention !



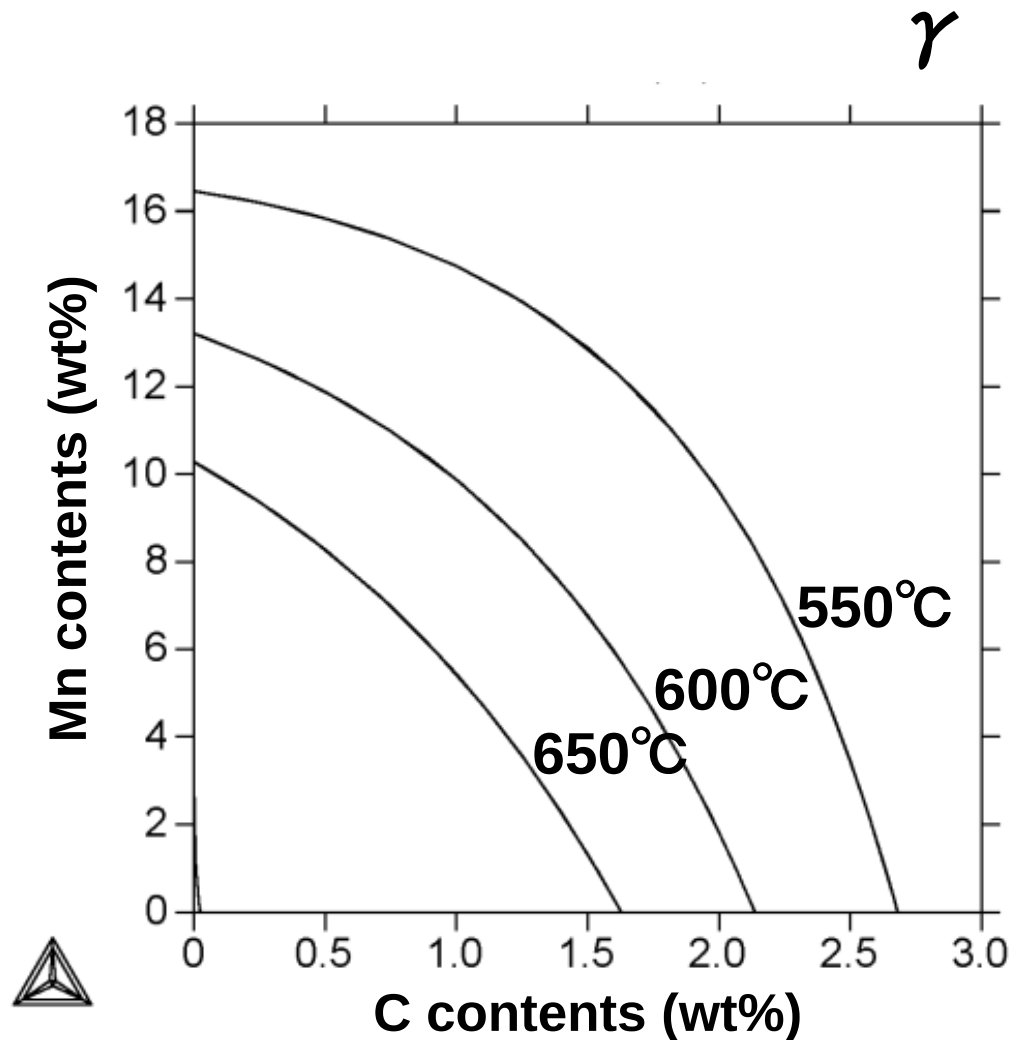
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Equilibrium Phase Diagram



**Increase in Mn content → Decrease in C content
in austenite**