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Publication date
2019

Document Version
Final published version

Citation (APA)
Ayenampudi, S., Celada-Casero, C., Sietsma, J., & Santofimia, M. J. (2019). *Effect of nickel on austenite stabilization during quenching and partitioning process in medium-Mn steels*. Material Science and Technology 2019, Portland, Oregon, United States.

European Commission

HIGHQP- RFCS ’15

Effect of nickel on austenite stabilization during quenching and partitioning process in medium-Mn steels

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MS&T19
MATERIALS SCIENCE & TECHNOLOGY
SEPTEMBER 29 - OCTOBER 3, 2019
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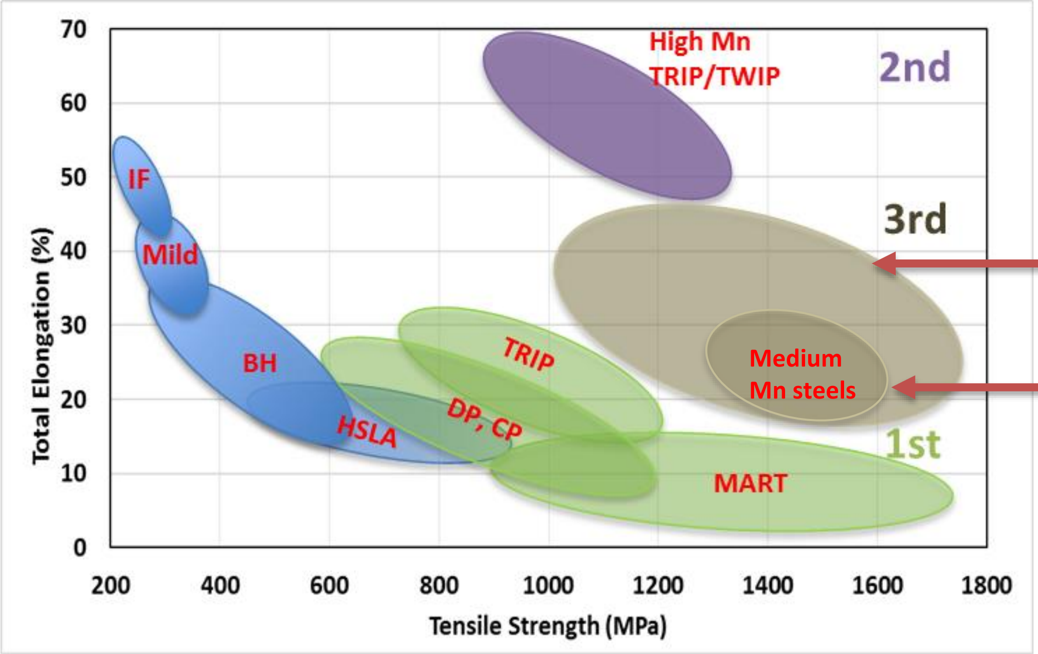
Introduction : 3rd generation AHSS

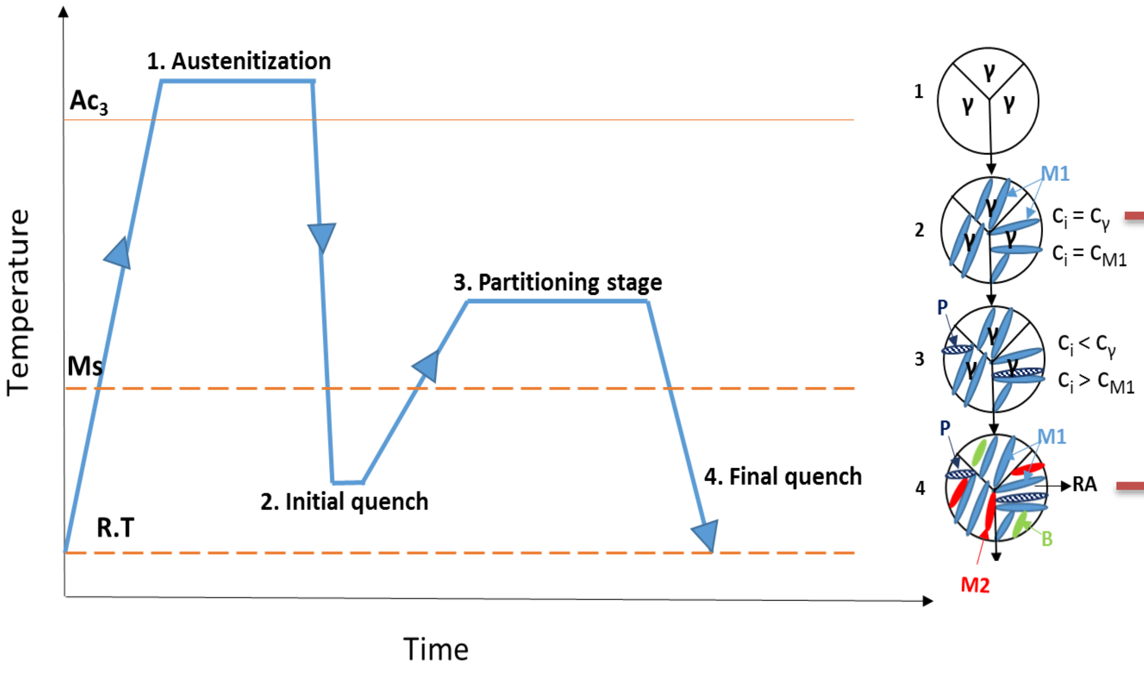


- Quenching & partitioning (Q&P) process: Combination of high strength and ductility

- Medium Mn steels are considered as potential candidates for 3rd generation AHSS

- Strong austenite (γ) stabilizers – C, Mn, Ni.

Introduction: Quenching & partitioning (Q&P) process



Partitioning of interstitial/substitutional alloying elements from martensite ($\alpha^{|}$) to austenite (γ)

Retained austenite (RA): Ductility

Martensite (primary & fresh): Strength

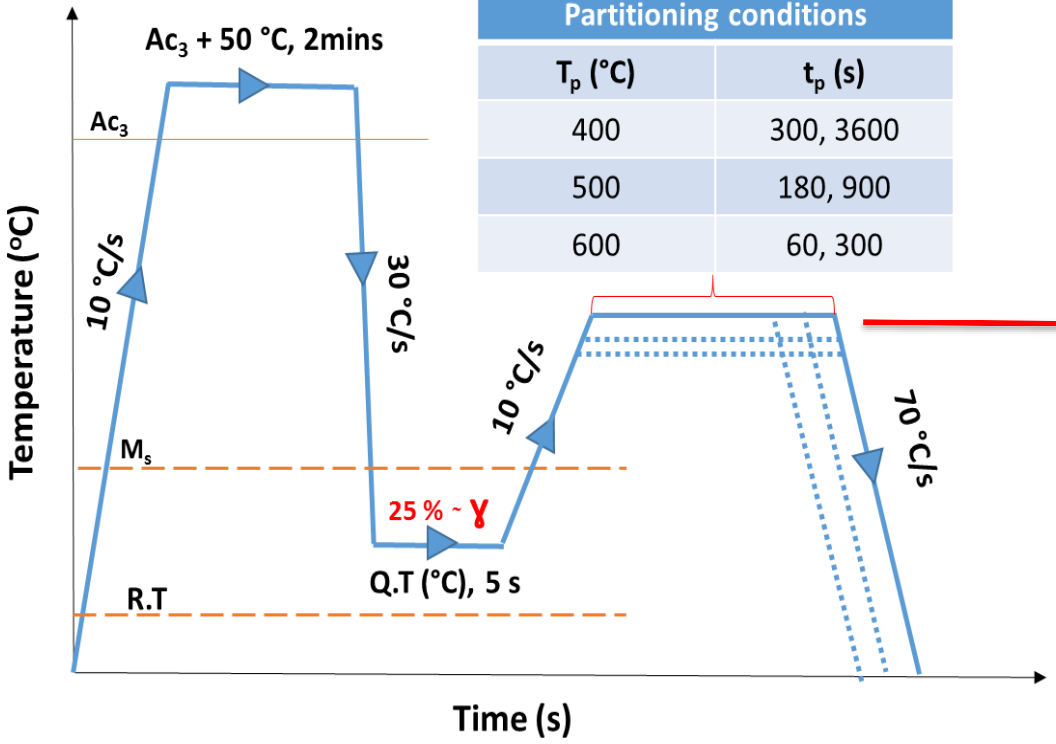
Ac_3 – Austenite finish temperature, Ms - Martensite start temperature, R.T. – Room temperature

Research Objective

In this study, we investigate:

Effect of nickel on austenite stabilization during Q&P process in medium-Mn steels.

Approach: Experiments & characterization techniques



Partitioning conditions	
T_p (°C)	t_p (s)
400	300, 3600
500	180, 900
600	60, 300

Steel compositions in wt.%:

- **Alloy *Mn*: 0.19C-6.0Mn**
- **Alloy *MnNi*: 0.19C-6.0Mn-2.1Ni**

Reactions competing for carbon:

- Carbide precipitation
- Alloying element (C/Mn) partitioning
- Phase transformations

Microstructure characterization

- **Dilatometry**
- **Scanning electron microscopy (SEM)**
- **X-ray diffraction (XRD)**

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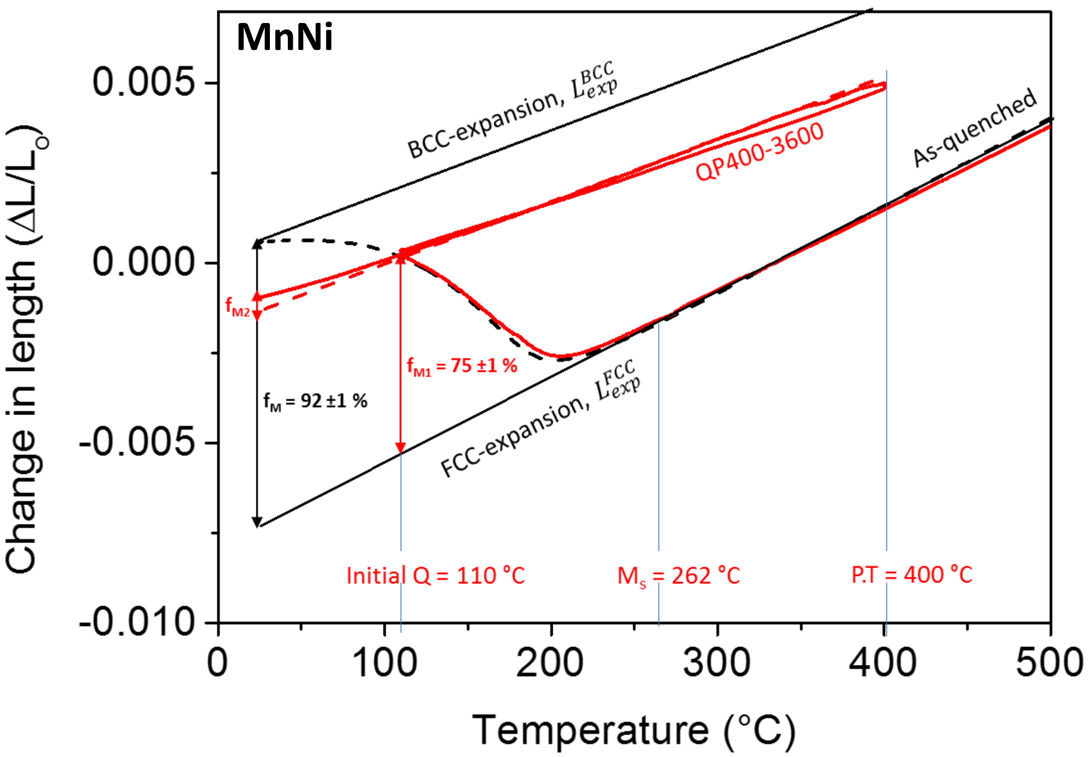
Ac_3 – Austenite finish temperature, Ms - Martensite start temperature, R.T. – Room temperature

Quantification of phase fractions and carbon



Fractions of phases

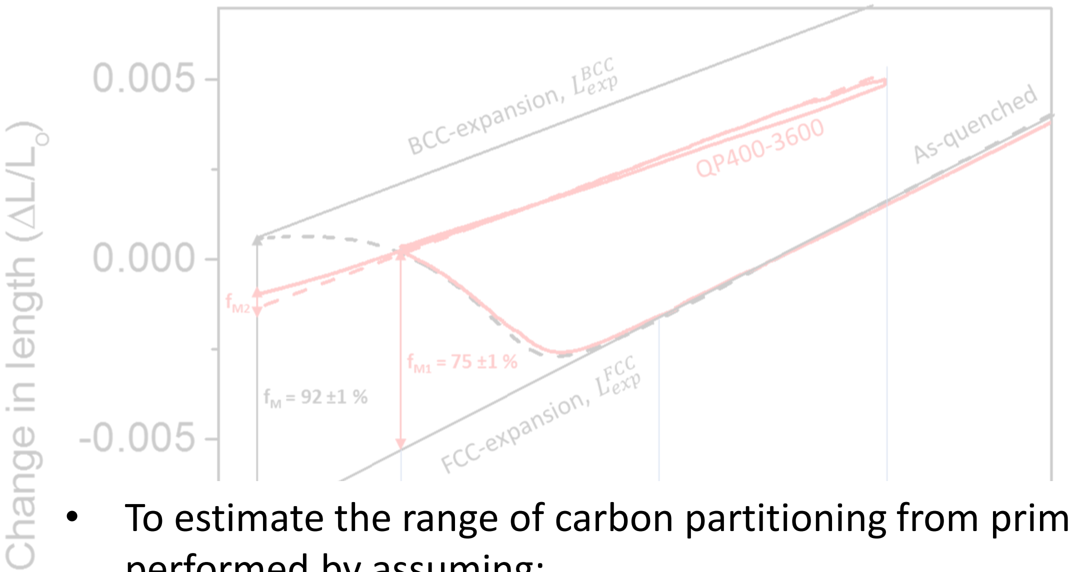
- Retained austenite: XRD
- M1 and M2: Lever rule on dilatometry data.
- Pearlite (when present): $f_{M1} + f_{M2} + f_{RA} + f_p = 1$

Carbon content

- Carbon in M2: Upper & Lower limits

M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite; P - Pearlite

Quantification of phase fractions and carbon



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- Carbon content
  - Carbon in M2: Upper & Lower limits

- To estimate the range of carbon partitioning from primary martensite to austenite carbon balance is performed by assuming:
  - carbon content in M2 is same as in RA: **Upper limit**
  - carbon content in M2 is same as nominal composition **(0.19 wt. %)**: **Lower limit**

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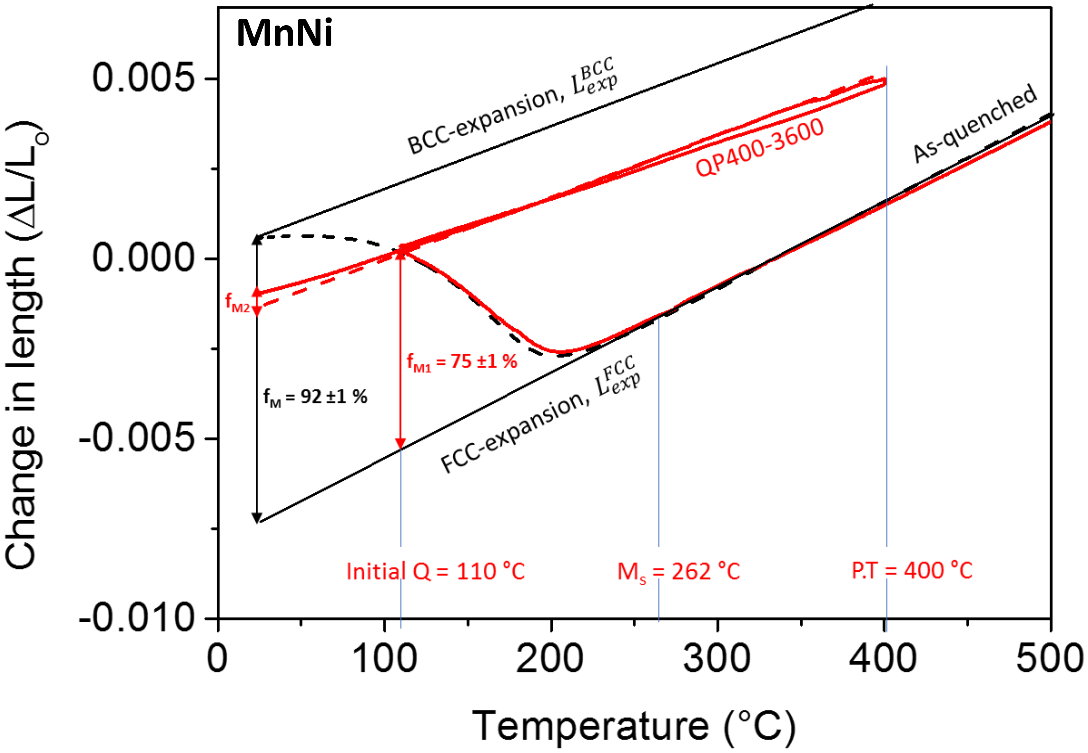
M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite

Quantification of phase fractions and carbon



➢ Fractions of phases

- Retained austenite: XRD
- M1 and M2: Lever rule on dilatometry data.
- Pearlite (when present): $f_{M1} + f_{M2} + f_{RA} + f_p = 1$

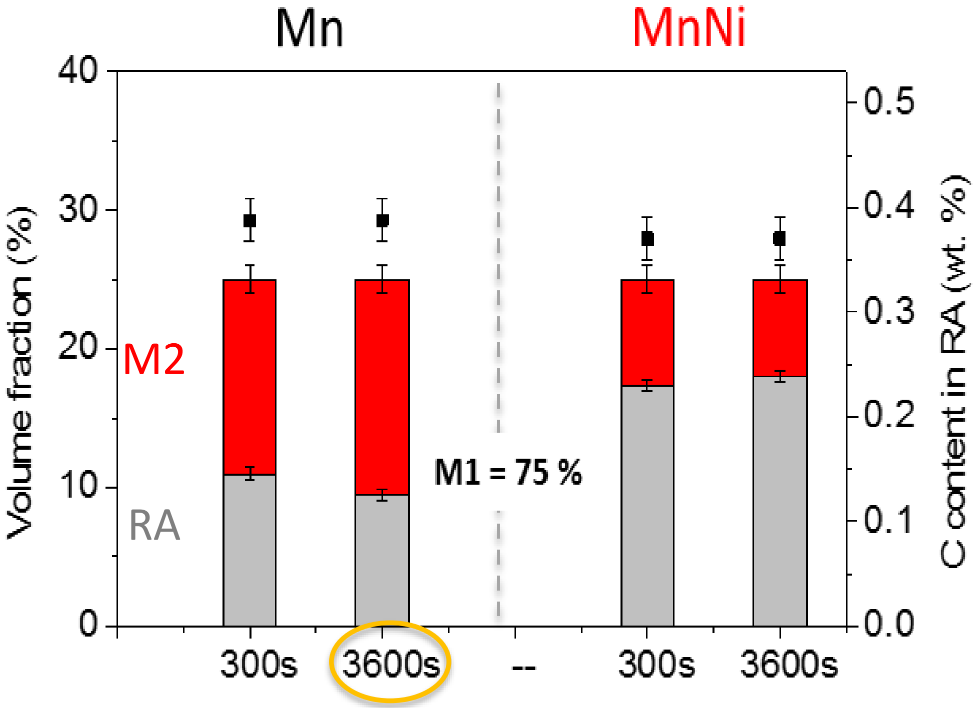
➢ Carbon content

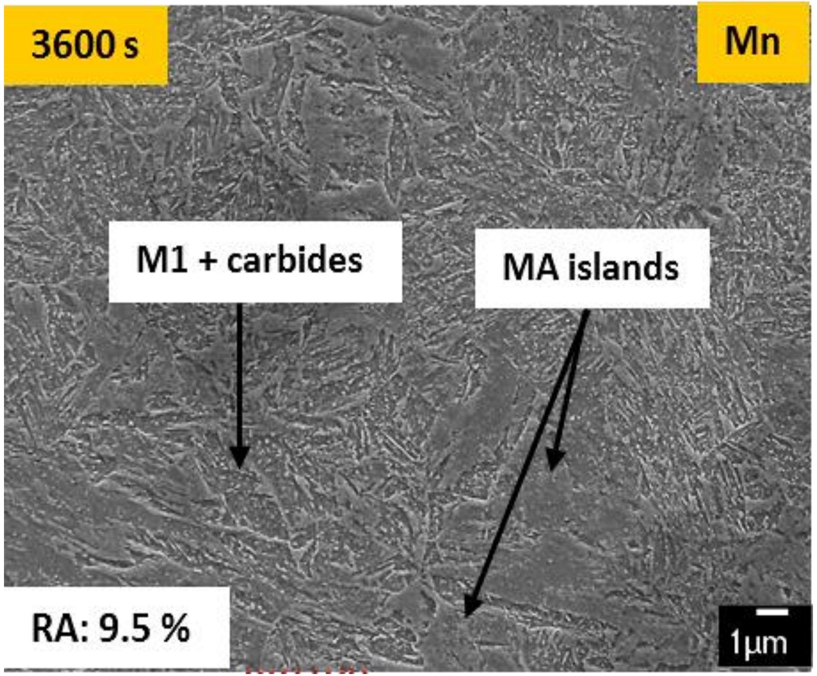
- Carbon in M2: Upper & Lower limits
- Carbon in M1: All carbon in M1, including solid solution and carbides, from carbon balance.

$$\dot{x} = f_\gamma \cdot x_c^\gamma + f_{M2} \cdot x_c^{M2} + f_{M1} \cdot x_c^{M1} + f_p \cdot x_c^p$$

M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite; MA – Martensite/Austenite;

Results - QP400





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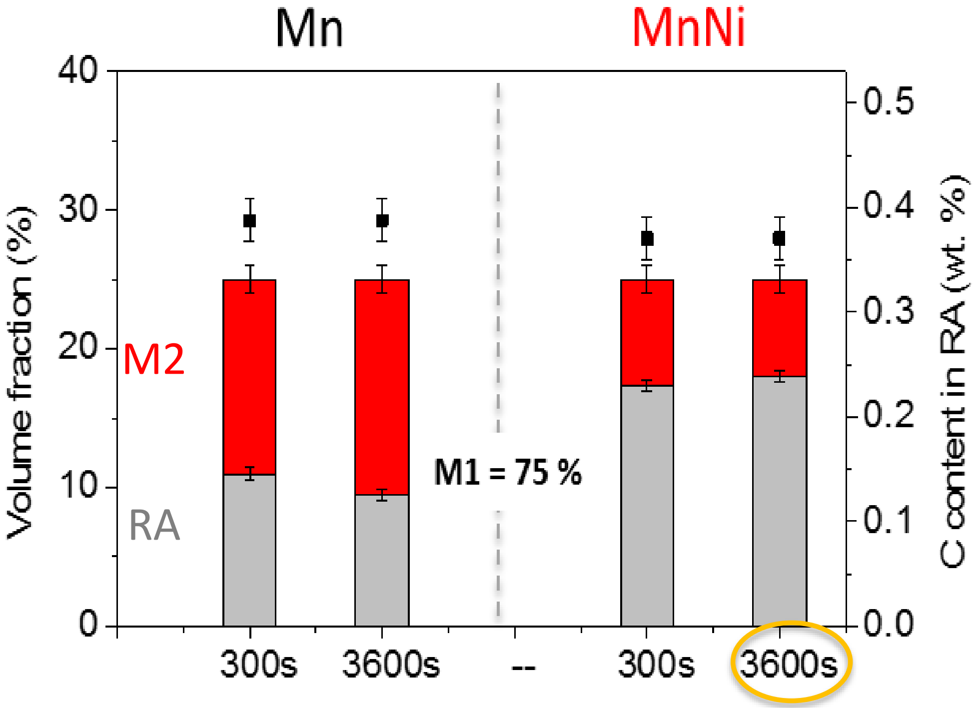
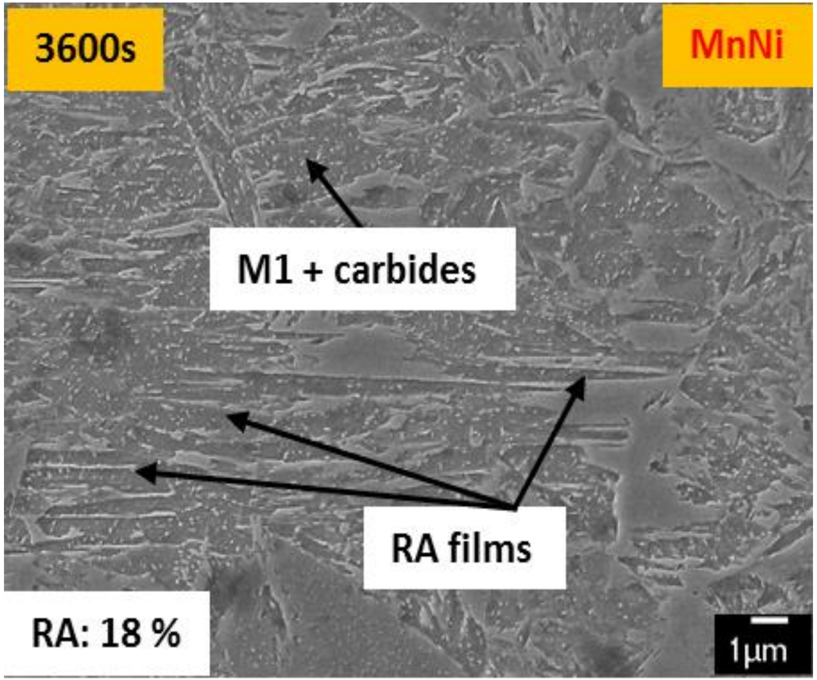
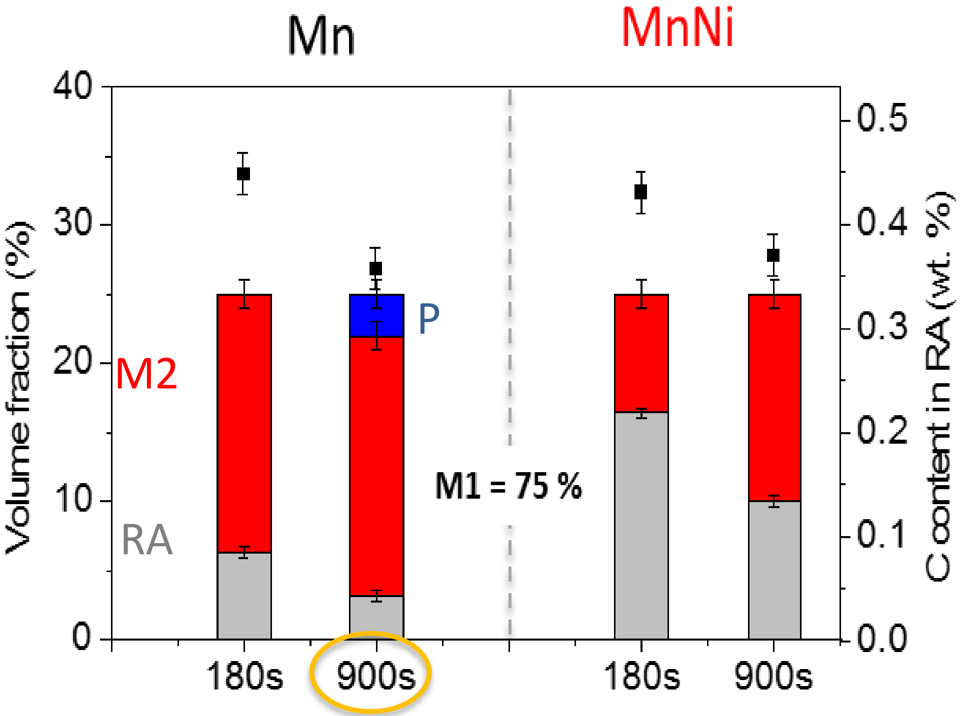
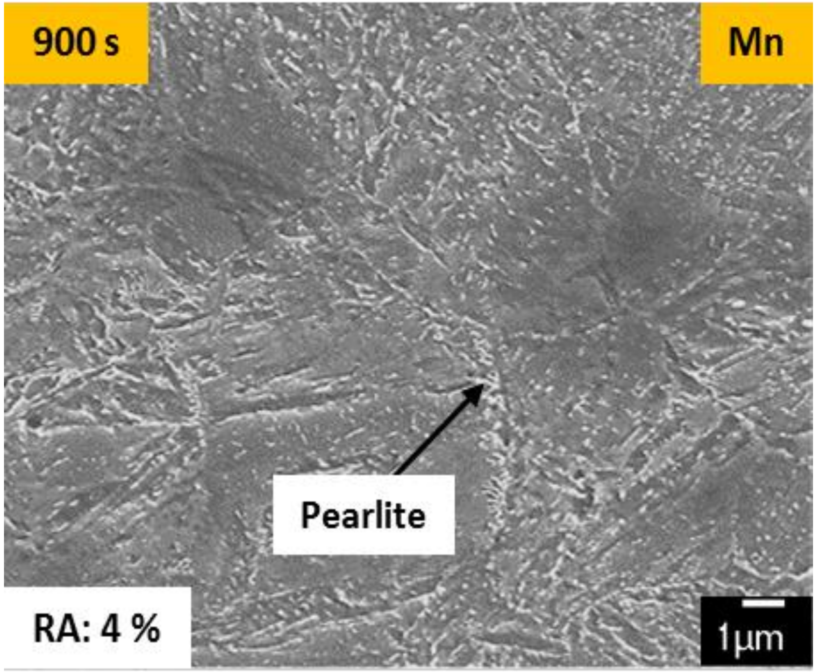




M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite;

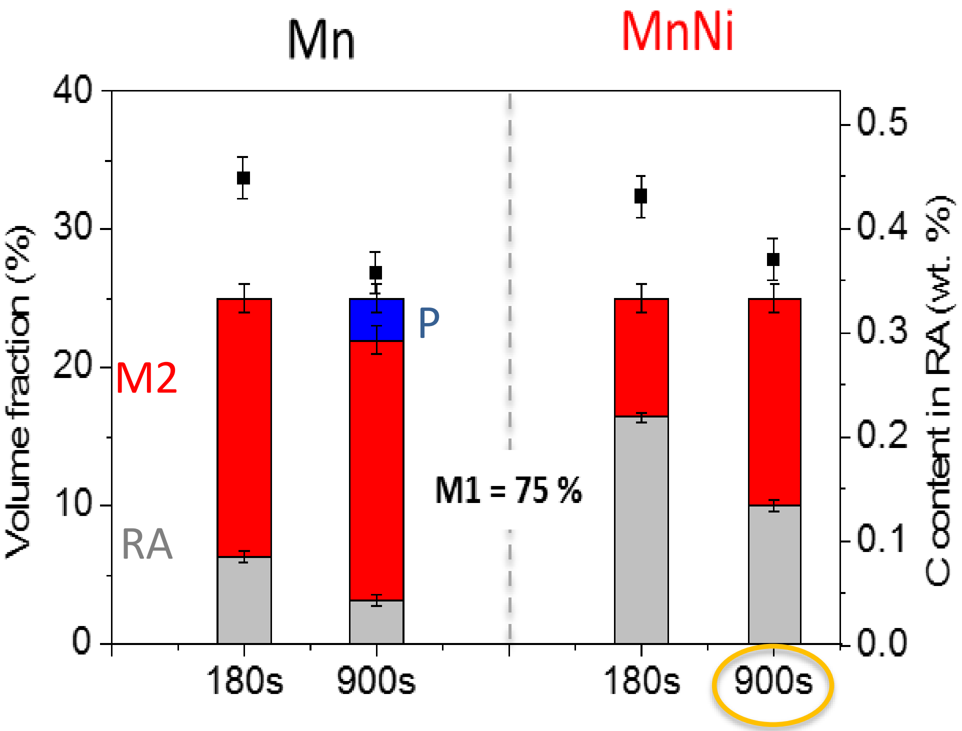
Results – QP500

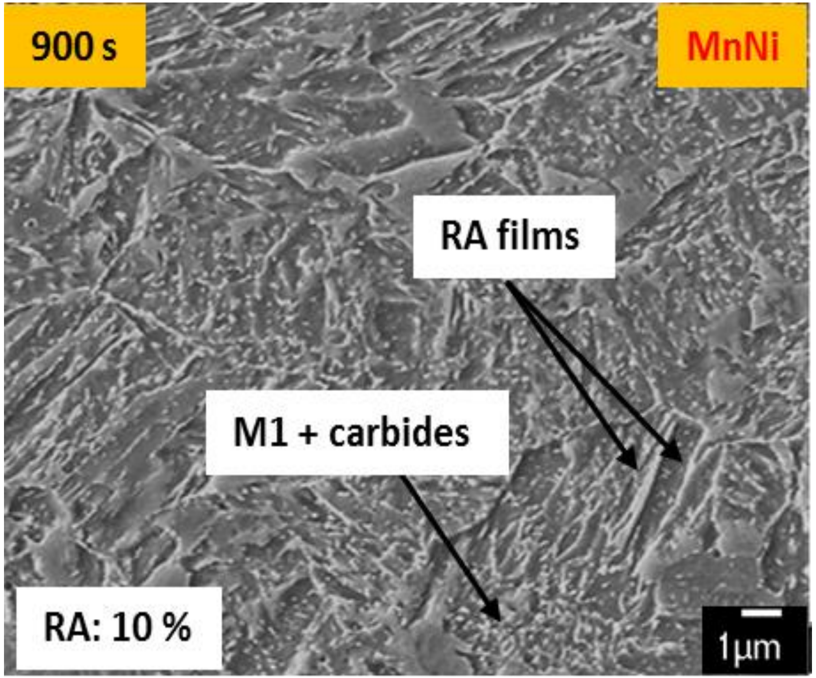




M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite; P - Pearlite

Results – QP500

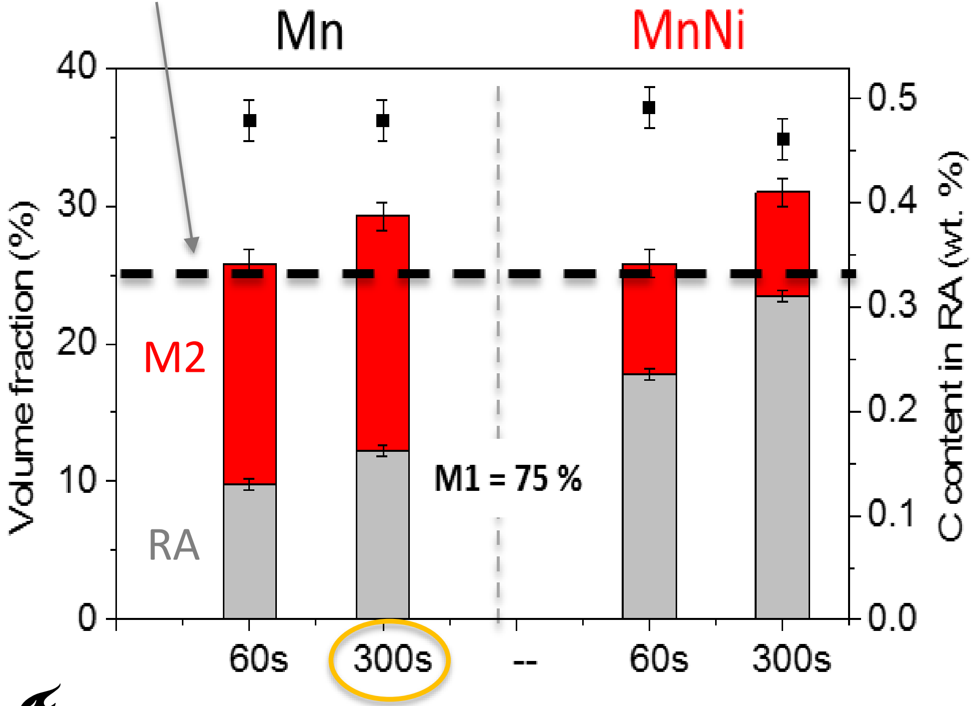


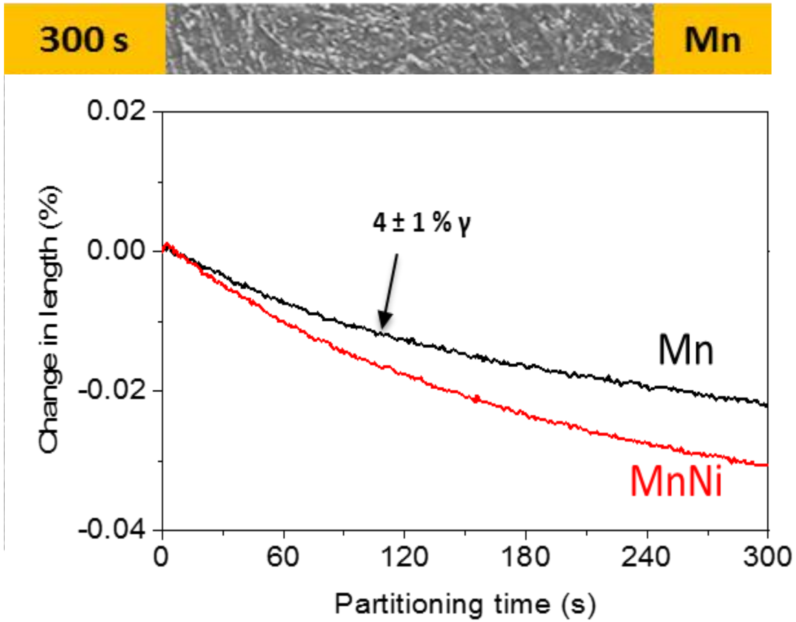


M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite; P - Pearlite

Results – QP600

Austenite fraction untransformed at T_Q





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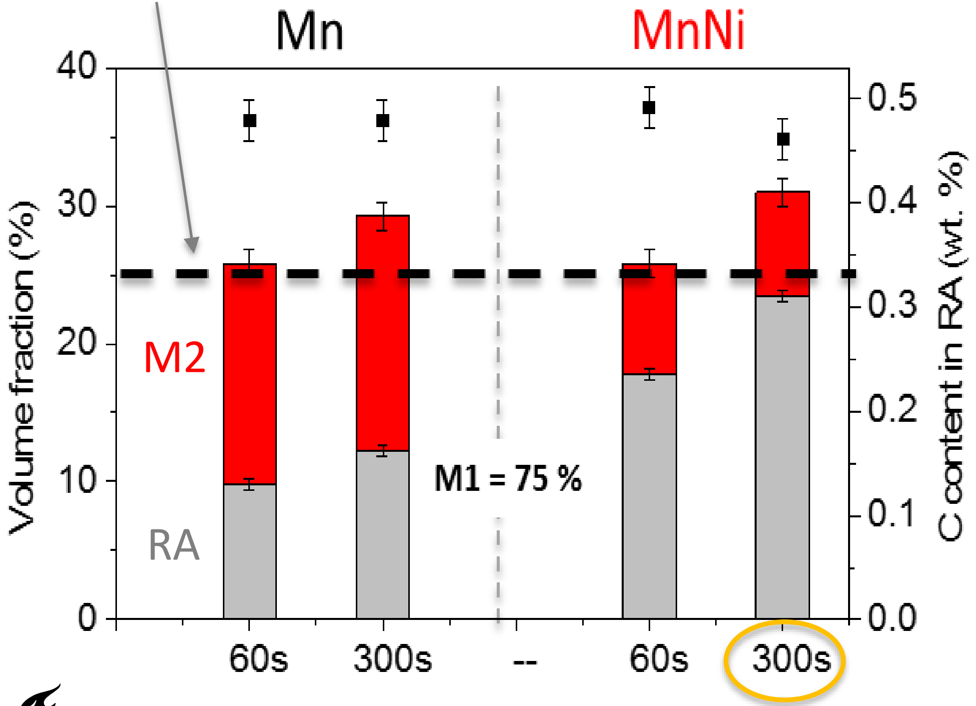
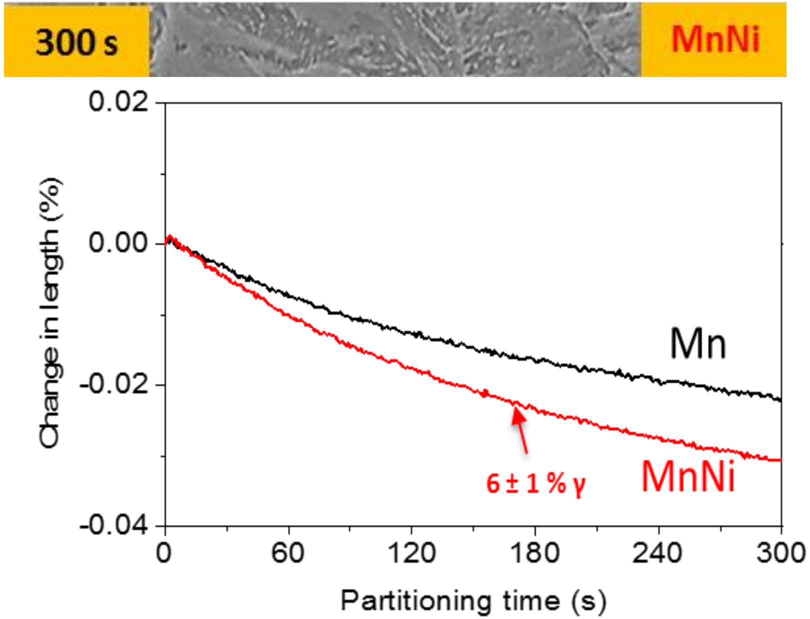
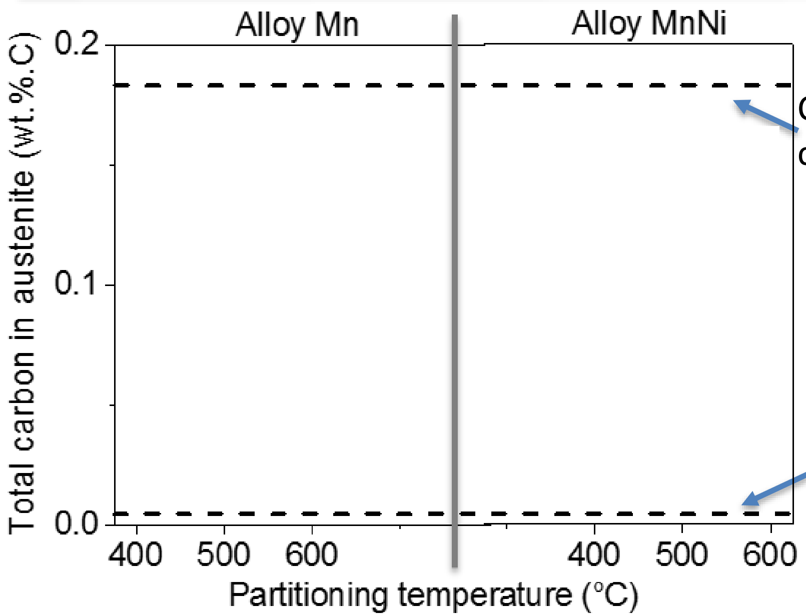




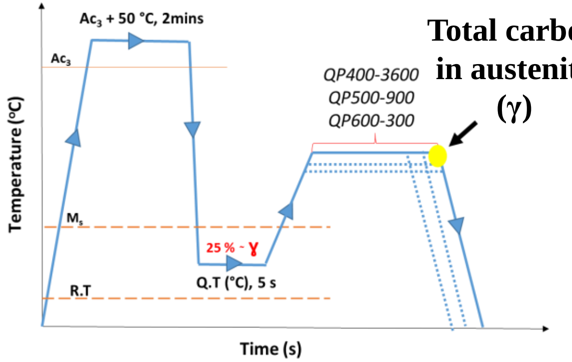
M1 – Primary martensite; M2 – Fresh martensite; RA – Retained austenite

Discussion



Carbon content in γ assuming complete partitioning (0.18)

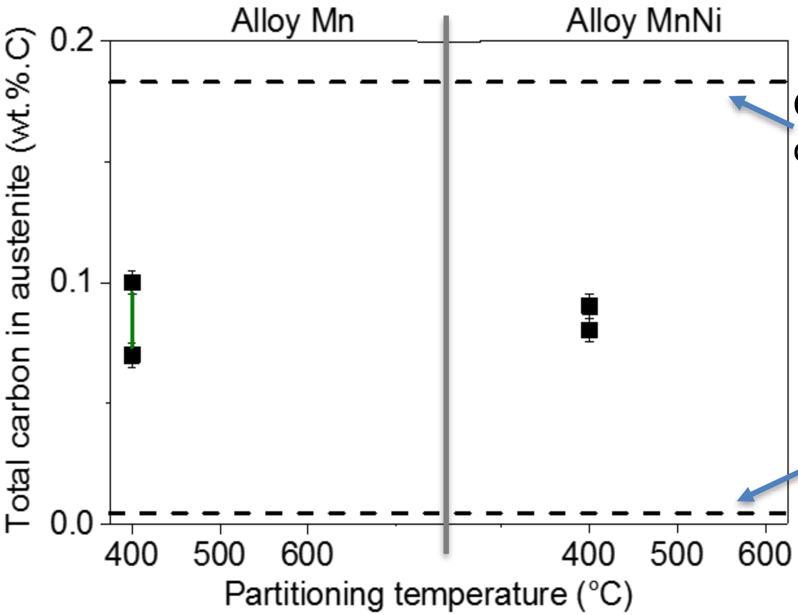
Carbon content in γ at the beginning of partitioning step (0.04)



Total carbon in austenite (γ)

- To estimate the range of carbon partitioning from primary martensite to austenite carbon balance is performed by assuming:
  - ➢ carbon content in M2 is same as in RA: **Upper limit**
  - ➢ carbon content in M2 is same as nominal composition **(0.19 wt. %)**: **Lower limit**

Discussion: QP400



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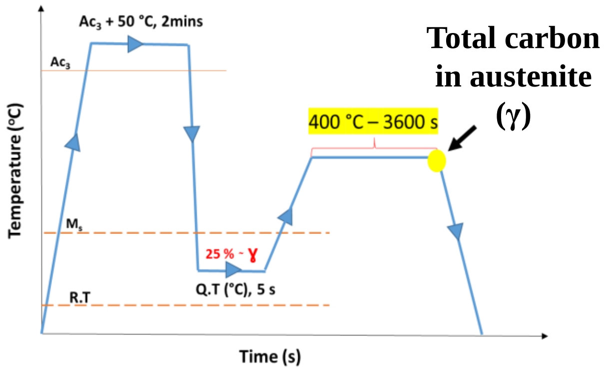
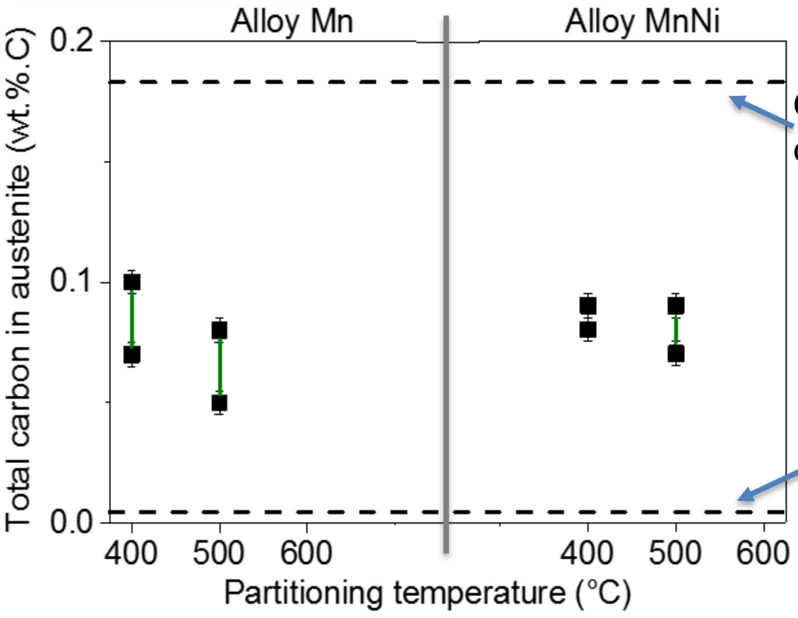


Alloy	Mn	MnNi
RA (±0.4 %)	9.5	18

- Not all carbon is partitioned into austenite. A fraction of carbon remains in M1 in solid solution or in the form of carbides.

Discussion: QP500



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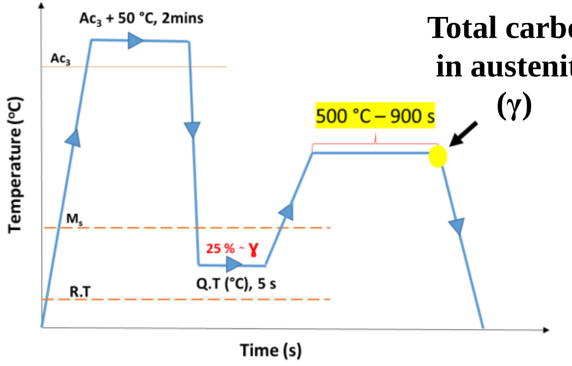
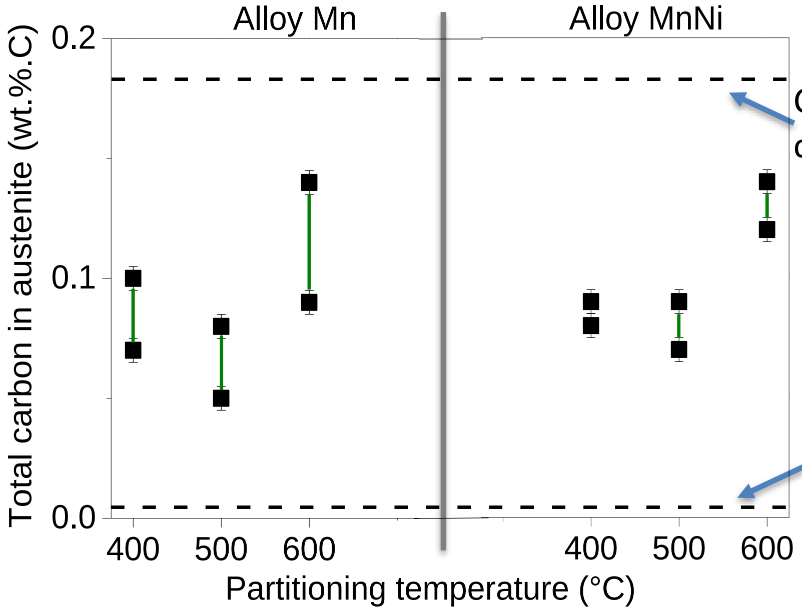


Total carbon in austenite (γ)

Alloy	Mn	MnNi
RA (±0.4 %)	4	10

- In alloy *Mn*, a fraction of carbon is also consumed by pearlite (~ 0.02 wt. % C).
- Hence, the austenite in alloy *Mn* is enriched with lower carbon content than in alloy *MnNi.*

Discussion: QP600



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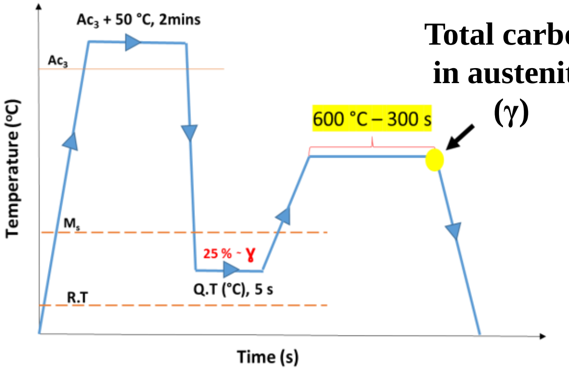


Total carbon in austenite (γ)

Alloy	Mn	MnNi
RA (±0.4 %)	12	24

- Compared to lower partitioning temperatures, due to ART, more carbon is present in austenite.

Summary: austenite stabilising effect of nickel

- **Depending on the partitioning temperature , the austenite stabilising effect of nickel influences the processes competing for carbon.**

Tp (°C)	Influence of nickel
400	Results in higher f_{RA} by decreasing the carbon content required to stabilize austenite at room temperature
500	Prevents the formation of pearlite, resulting in higher f_{RA} with higher x_c^{RA}
600	Promotes a faster formation of reverse austenite, resulting in higher f_{RA}

M1 – Primary austenite, RA – Retained austenite, f_{RA} and x_c^{RA} – fraction and carbon content of retained austenite.

Conclusions

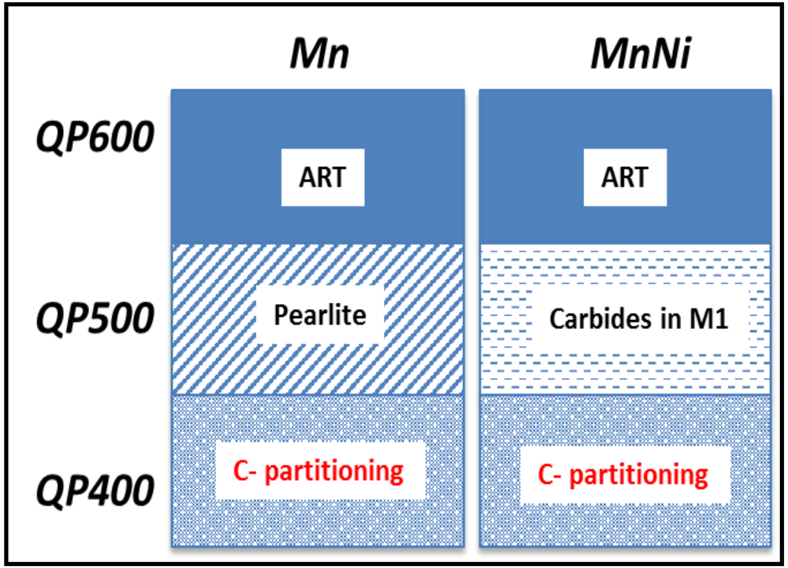
- **This research investigates the effect of nickel on austenite stability at standard-high partitioning temperatures in medium Mn steels**

1) At all partitioning temperatures, a fraction of carbon is present in primary martensite in solid solution or in the form of carbides.

2) Presence of nickel hindered the major processes that consume available carbon during partitioning stage.

3) Alloy with nickel stabilizes higher fraction of retained austenite at all partitioning temperatures despite of lower carbon content.

Summary of major phenomenon at different P.Ts



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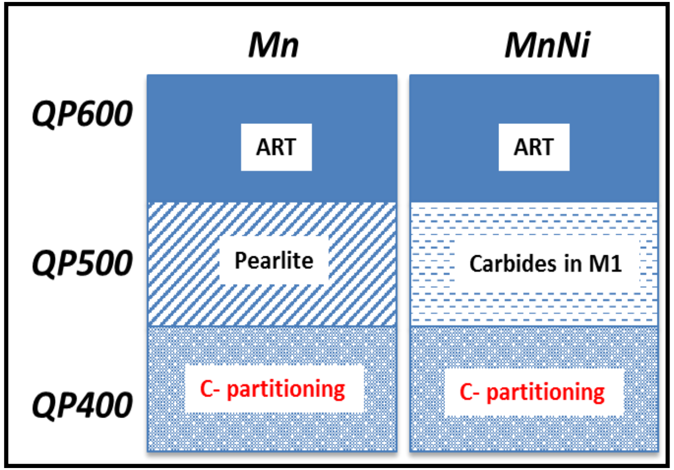

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