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Effect of niobium on microstructural and mechanical properties of the heat affected zones of welded E36 steel

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Outline

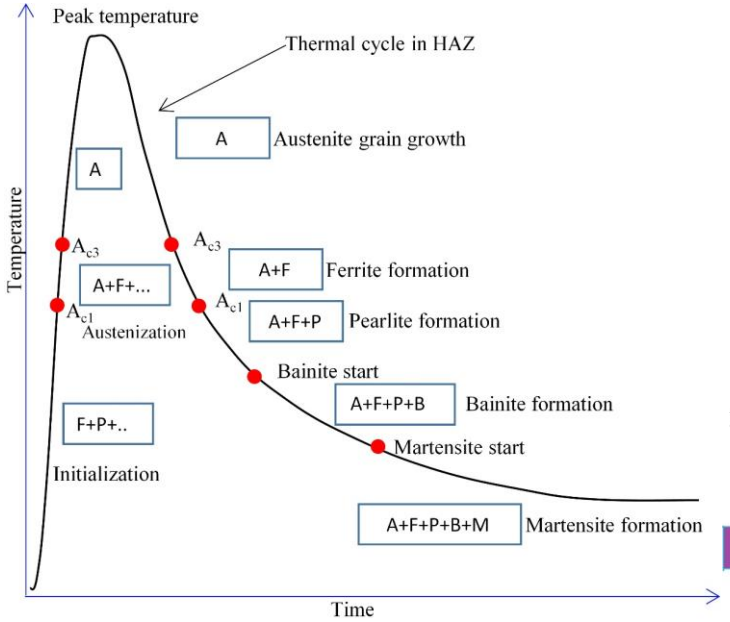
1 Background

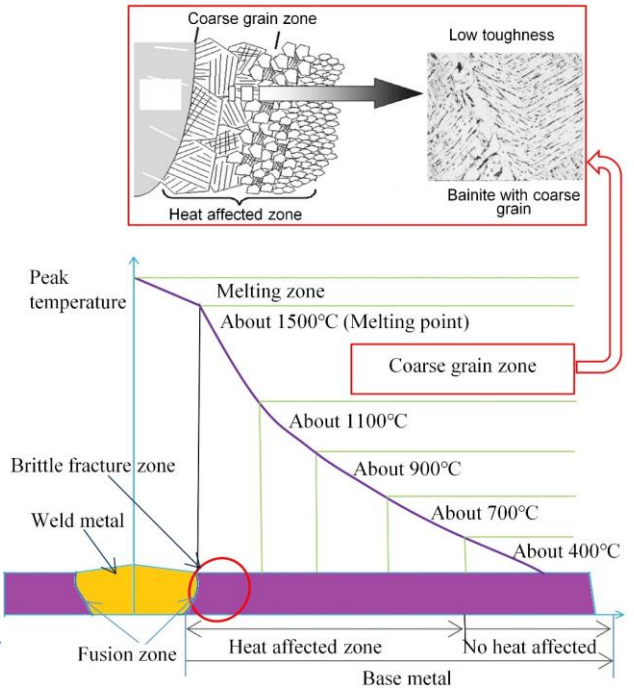
2 Microstructure and mechanical properties of coarse grain zone

3 Simulation of microstructure evolution based on SHCCT experiments

4 Summarize & Future work

Thermal history & phase transformation during high heat input welding (HHIW)

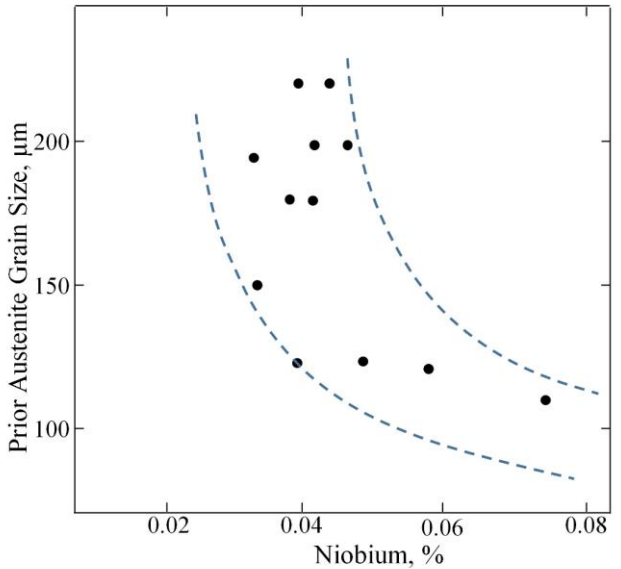




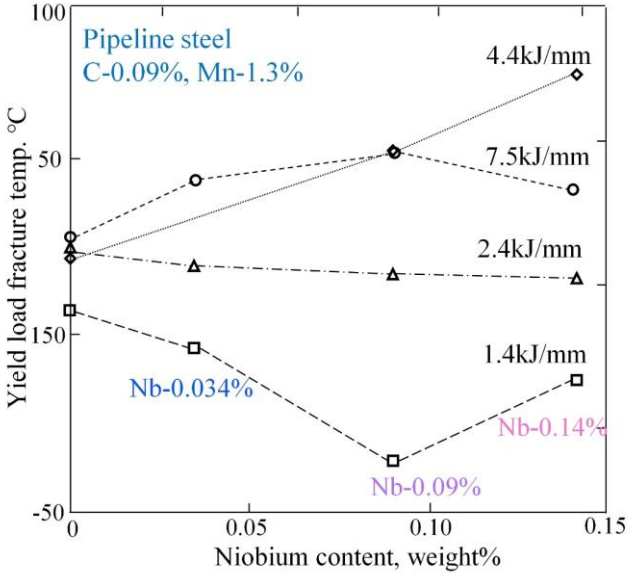
- Phase fraction & grain size determine the properties of the HAZ
- Coarse grain zone prone to brittle fracture after HHIW

Kitani, Y., et al. Welding in the World. 2007.

Effect of niobium on size & toughness of heat-affected zone



Effect of niobium on prior austenite grain size



Effect of niobium on toughness

- Increases of Nb leading to finer prior austenite grain size
- Effect of Nb on fracture transition are different under different heat input
- Effect of niobium at heat input up to 250kJ/cm has not been mentioned

Batte, A. Proc. Int. Symp. on 'Niobium'. 2001.

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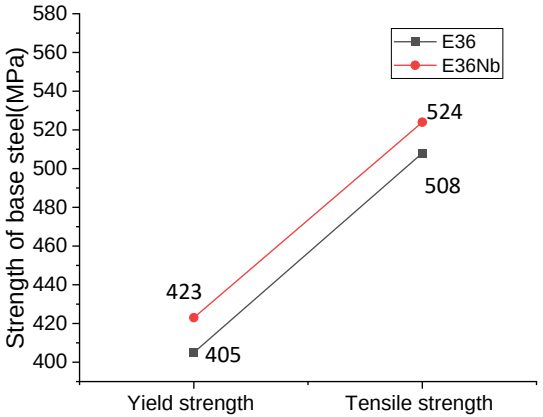
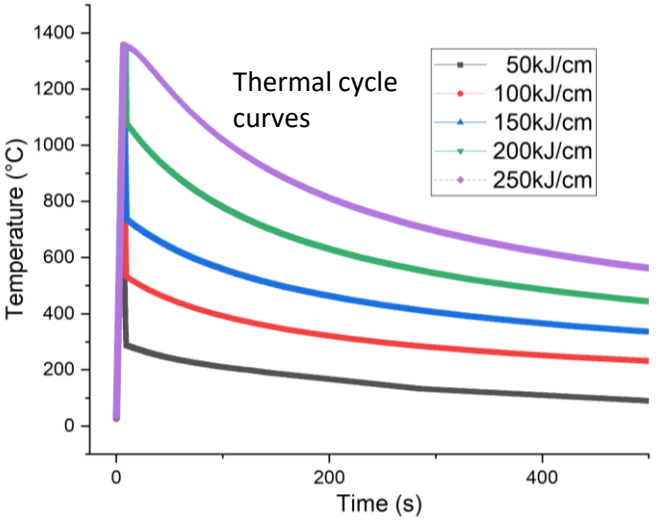
Coarse grain zone (HAZ) thermal experiments by Gleeble

Steel grade	Chemical composition of base steel					
	C	Mn	Si	**Nb**	Ti	Ceq
E36	0.081	1.51	0.21	/	0.016	0.34
E36-Nb	0.080	1.53	0.25	**0.012**	0.016	0.34

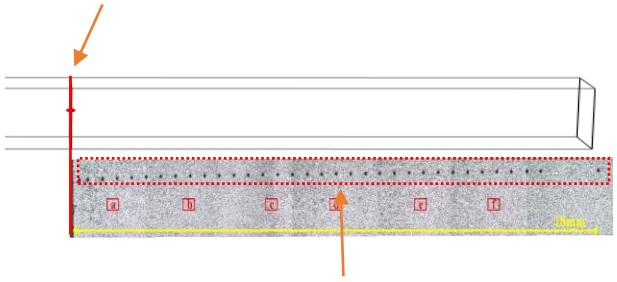
Parameter of coarse zone simulation			
Steel grade	Peak Temp (℃)	$\triangle t_{8/5}$ (s)	Heat input (kJ/cm)
E36& E36Nb	1350	17.8	50
		71.2	100
		160.1	150
		284.7	200
		444.8	250



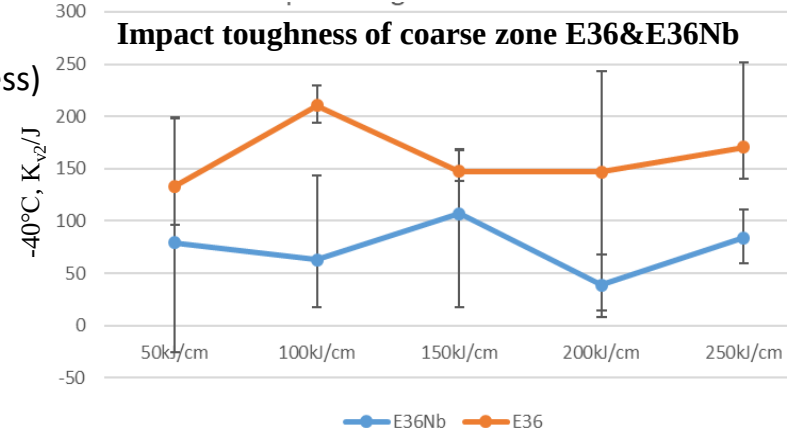


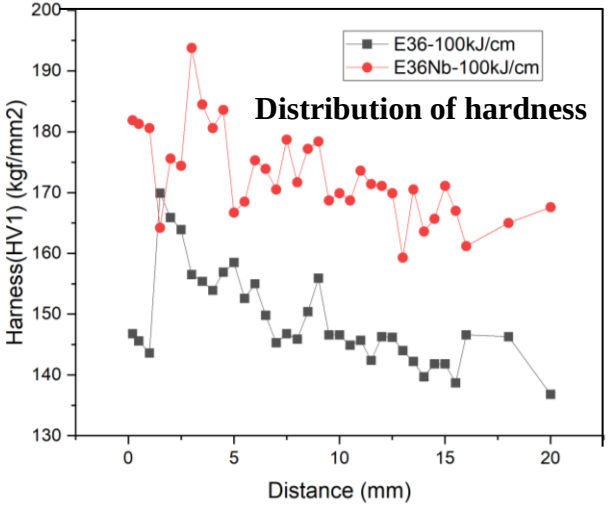
Mechanical properties of Coarse grain zone(HAZ) of E36 and E36Nb(experiments)

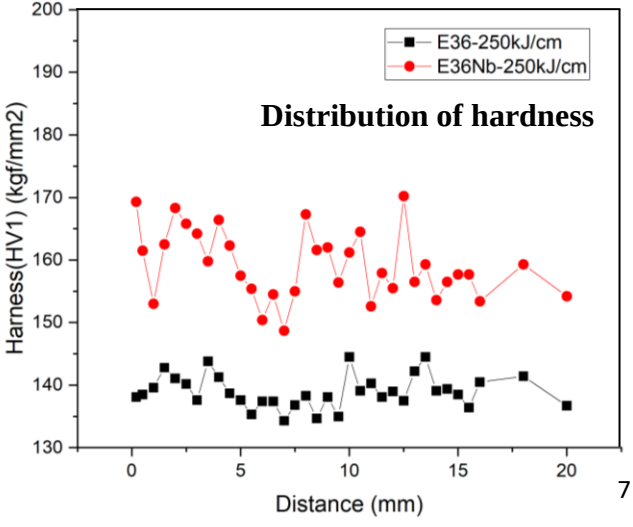
Centre line of the welding (Impact toughness)



Hardness test position



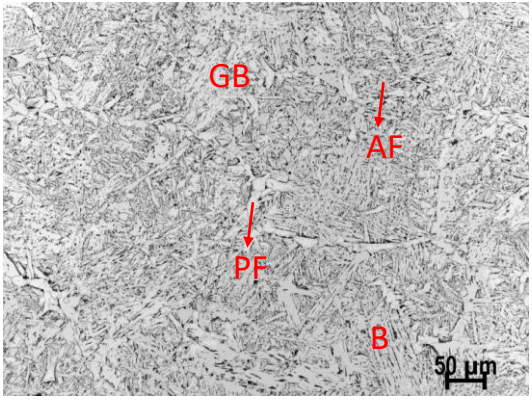




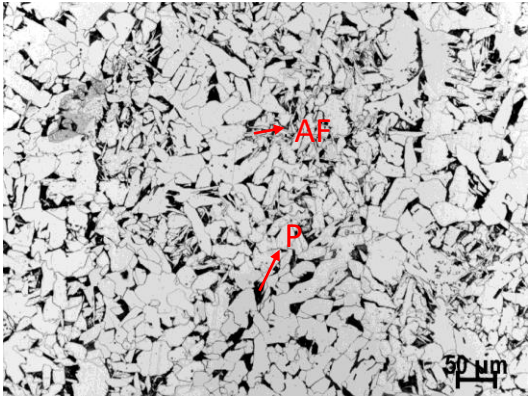
OM analysis of Coarse zone(HAZ) for E36 and E36Nb

E36-100: Bainite, Granular bainite & Acicular ferrite & Proeutectoid ferrite

E36-250: Proeutectoid ferrite, Acicular ferrite & Pearlite



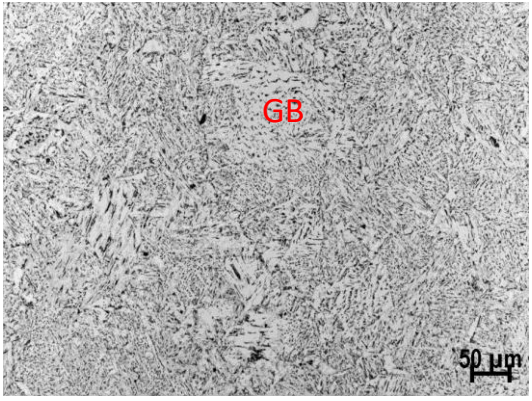
100kJ/cm E36



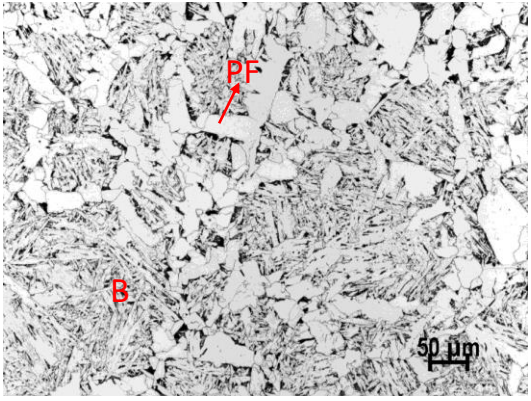
250kJ/cm E36

E36Nb-100: Mainly Granular bainite

E36-250: Bainite & proeutectoid ferrite

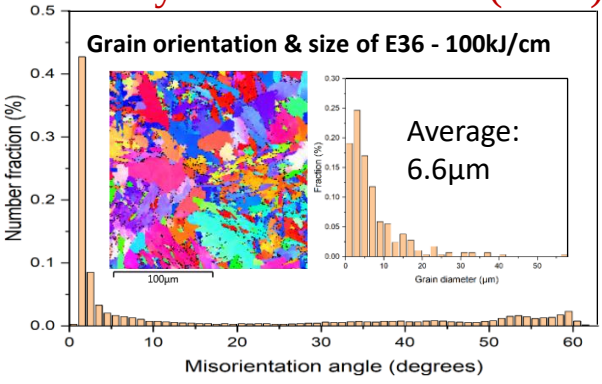


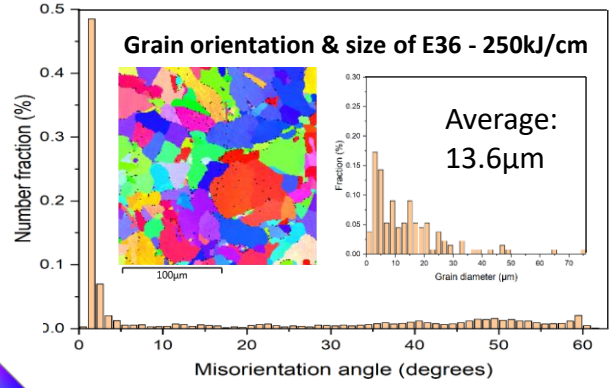
100kJ/cm E36Nb

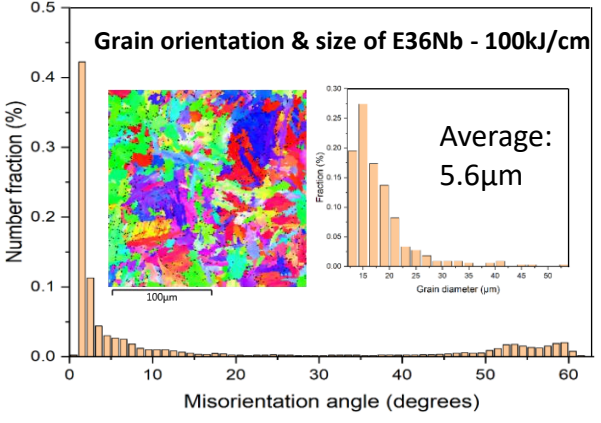


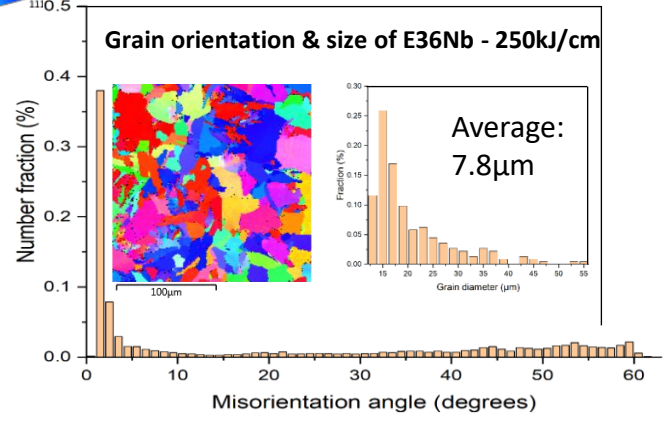
250kJ/cm E36Nb

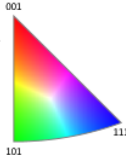
EBSD analysis of Coarse zone(HAZ)for E36 and E36Nb





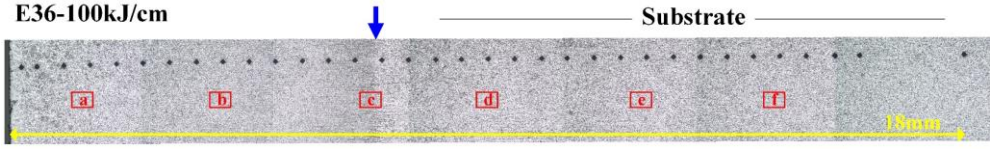


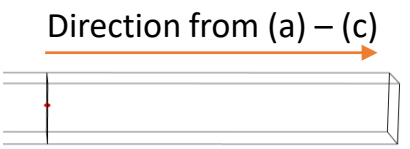


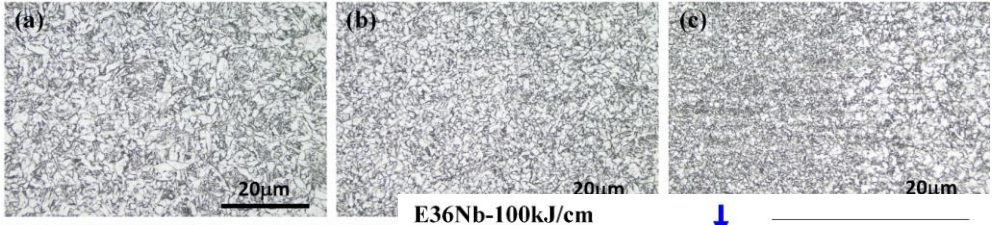


- Average grain size of E36Nb is finer than E36 with two heat input
- Average grain size coarse with higher heat input between 100kJ/cm and 250kJ/cm
- Percentage of small angle grain(Misorientation<15) of E36-100 is 66%, E36Nb-100 is 74%

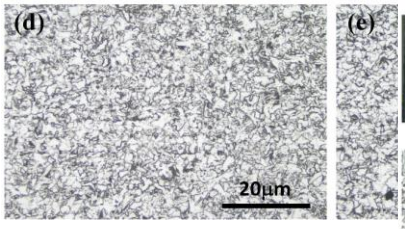
OM analysis of Coarse zone(HAZ) by horizontal position of sample

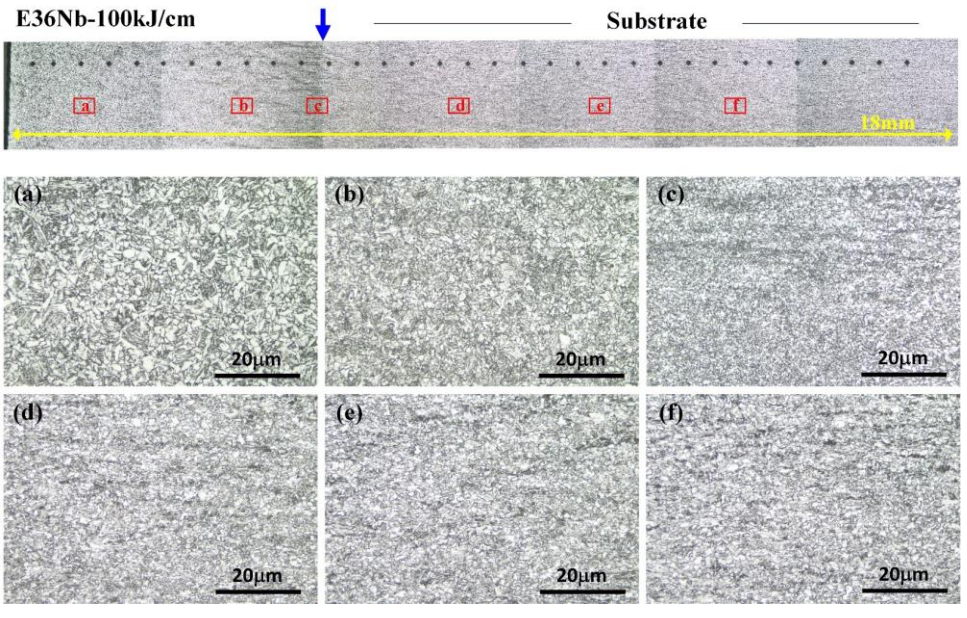






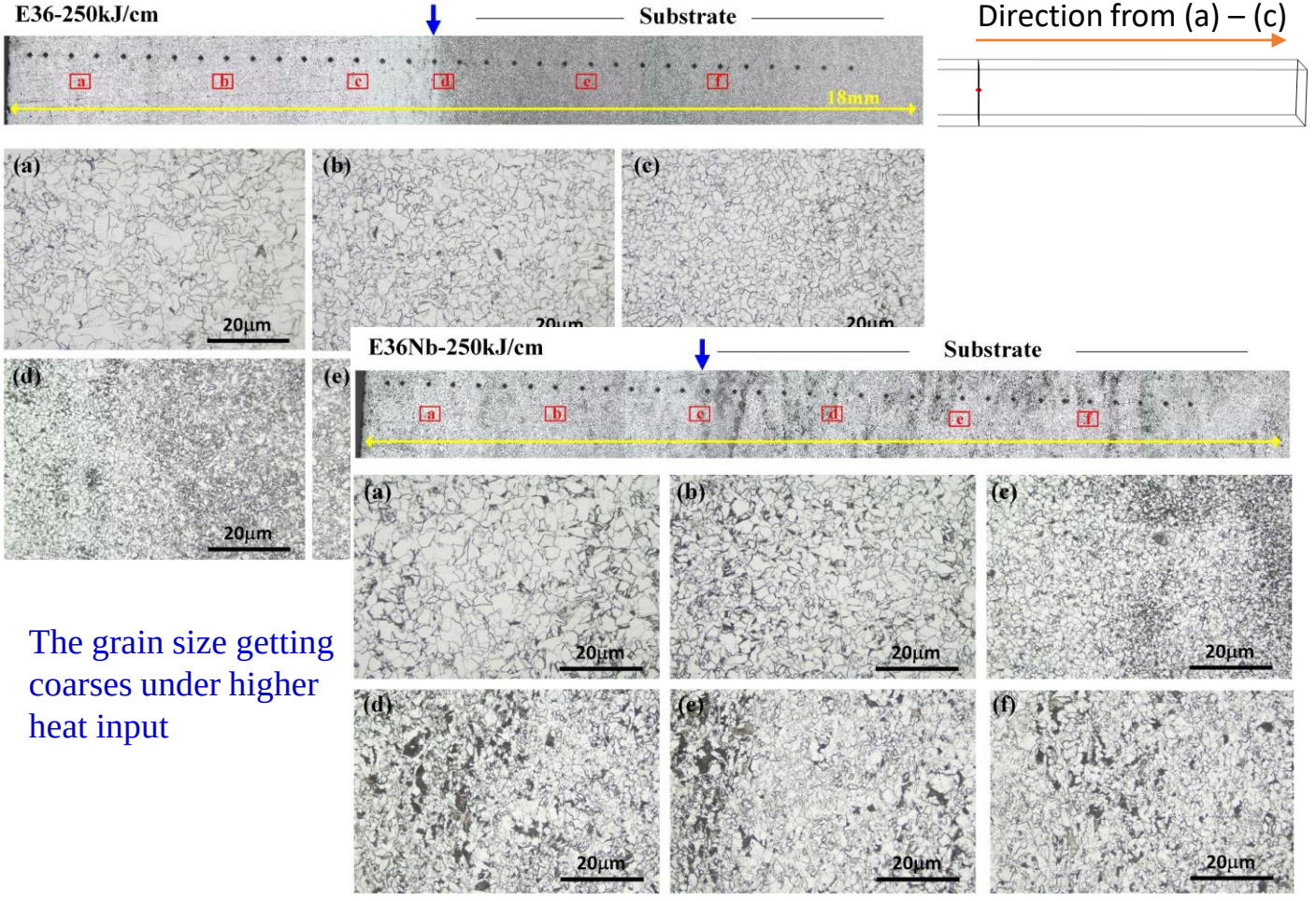
The gain size from coarse to fine with change of distance from center of welding





The gain size of E36Nb is finer than E36, and more bainite appeared in E36Nb

OM analysis of Coarse zone(HAZ) simulation by horizontal position of sample



The grain size getting coarses under higher heat input

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4 Summarize & Future work

Simulation (HAZ) continuous cooling transformation (SHCCT) curve of E36

F+P

↓

F+P+B

↓

PF+AF+B+P

↓

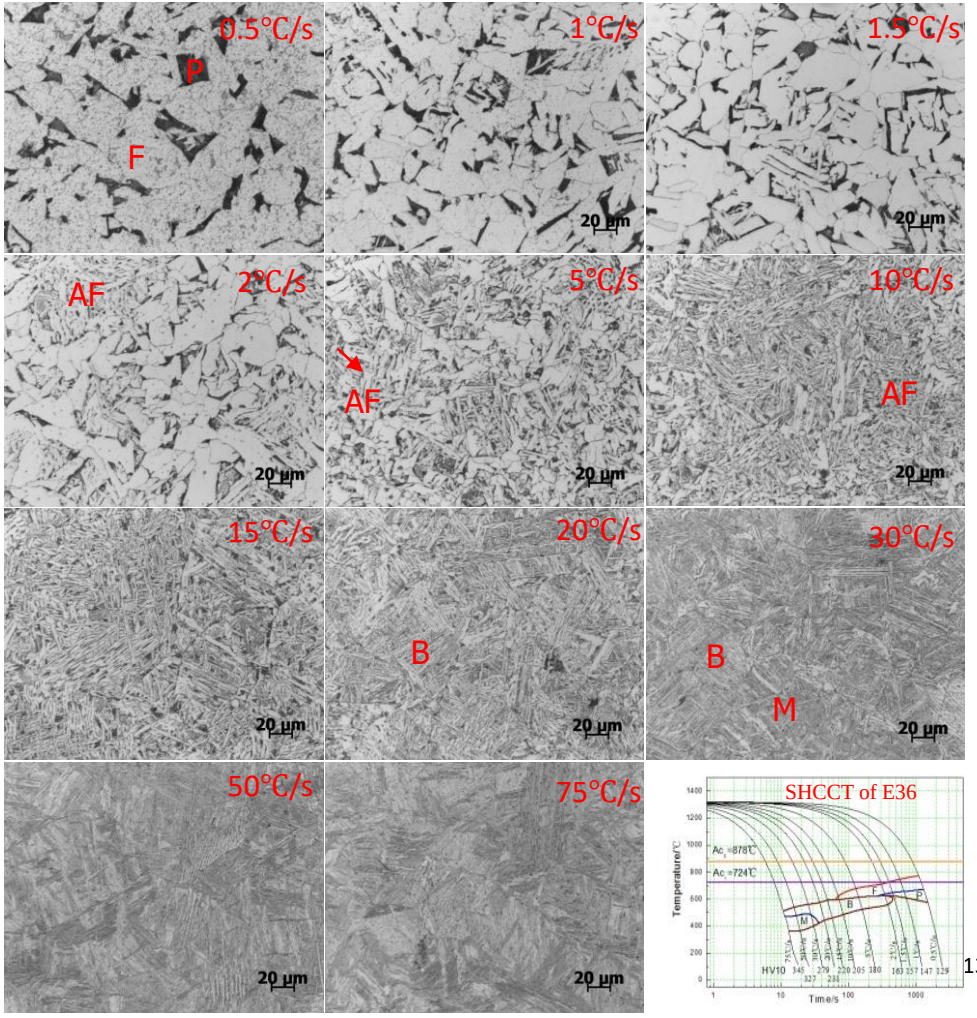
AF+PF+B

↓

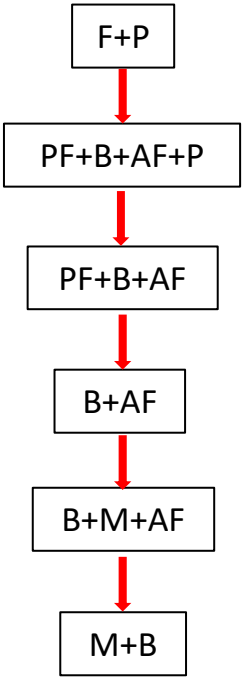
AF+B

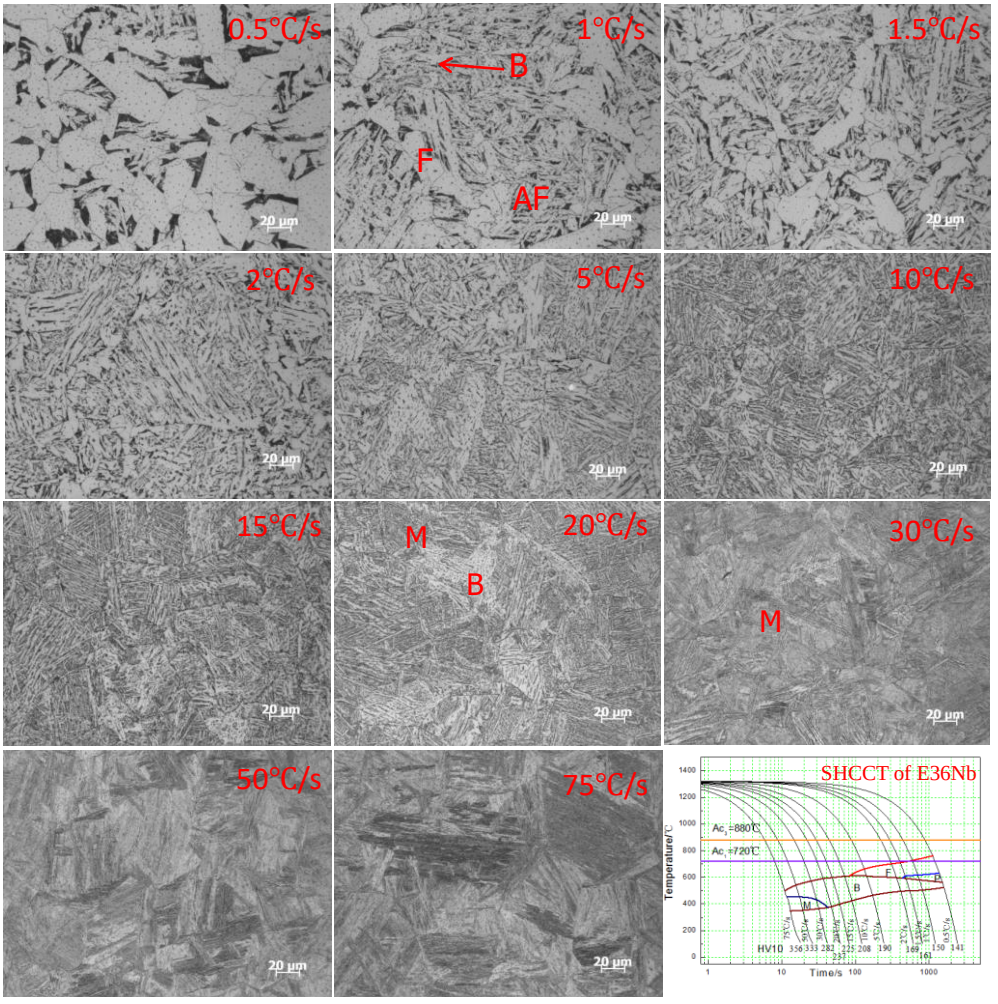
↓

M+B

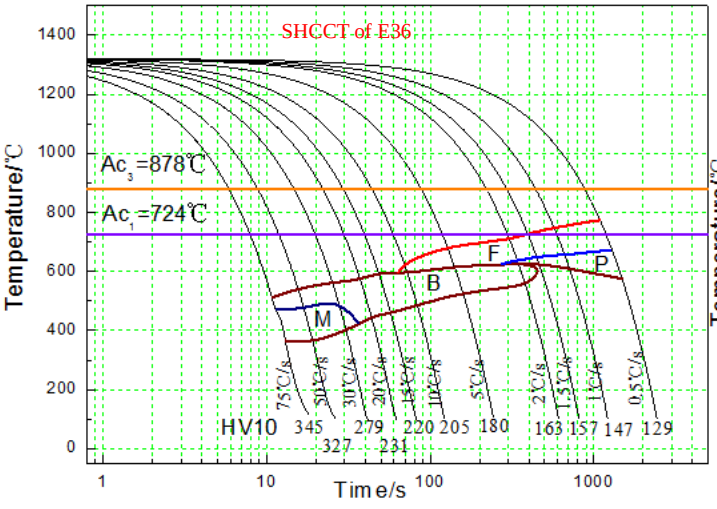


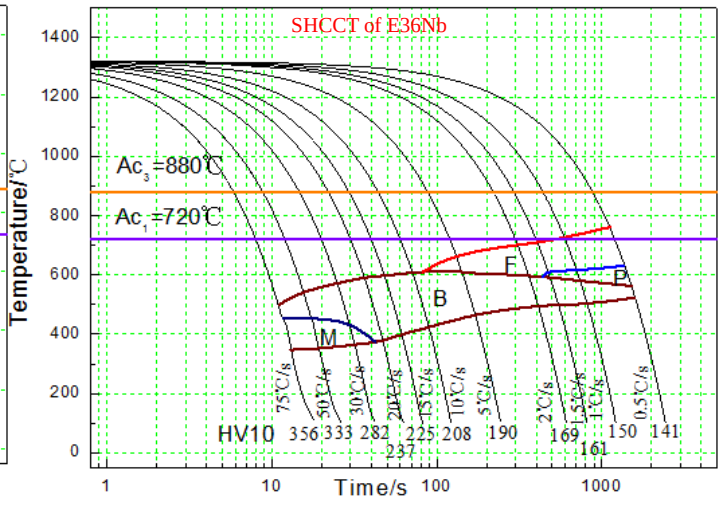
Simulation (HAZ) continuous cooling transformation (SHCCT) curve of E36Nb





Continuous cooling transformation (SHCCT) curves of E36 & E36Nb





- Niobium addition reduces the phase transition temperature (including the start transition temperature and end temperature)
- Niobium addition expands the bainite transformation area
- Cooling rate of acicular ferrite transformation from 2℃/s - 20℃/s for E36, 1℃/s - 2℃/s for E36Nb, Niobium addition reduced cooling rate range of acicular ferrite transformation

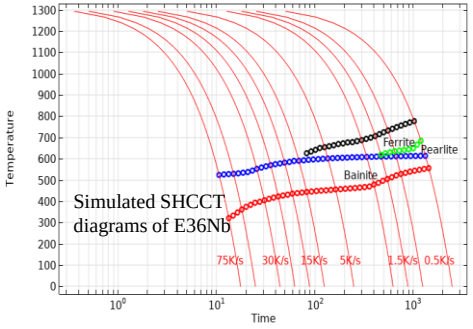
Leblond-Devaux equation and Koistinen-Marburger equation

Leblond-Devaux equation:

$$A_{s\to d} = K_{s\to d}\xi^{s} - L_{s\to d}\xi^{d}$$

ξ^{s} The ratio of consumption phase ξ^{d} The ratio of target phase

$K_{s\to d}$, $L_{s\to d}$ Temperature dependent function, $A_{s\to d}$ Phase evolution rate



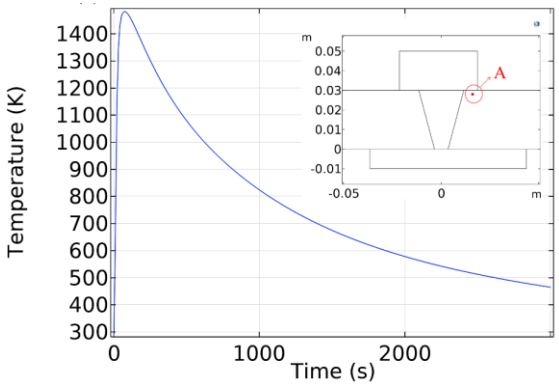
- Apply for austenite to ferrite, pearlite and bainite transformation
- Simulate the SH-CCT diagrams by COMSOL
- Adjust the $K_{s\to d}$ and $L_{s\to d}$ by comparison
- *K* and *L* in Leblond-Devaux equation was obtained according to corresponding phase transformation which described as interpolation functions

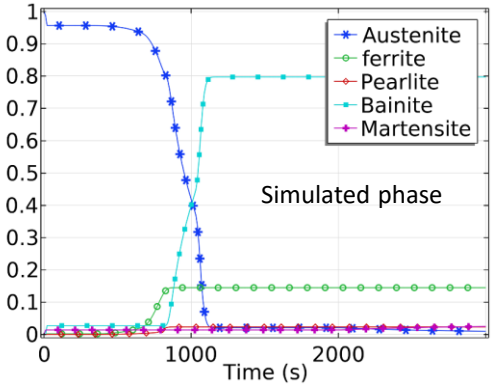
Temperature dependent functions of austenite decomposition

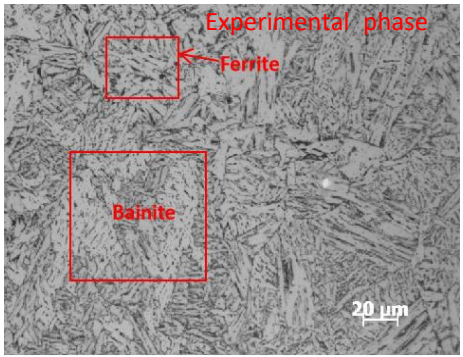
Temperature/°C	Austenite to ferrite		Austenite to bainite		Austenite to pearlite	
	K(1/s)	*L*(1/s)	*K*(1/s)	*L*(1/s)	*K*(1/s)	*L*(1/s)
0	0		0	0	0	0
300		0				0
520	0		0.05		0	
540			0.005			
560			0.005			
580				0.002		
600	0		0.005		0	
620				0.0002		
640	0.0012				0.0004	
650		0.0002				0.0002
710	0.00017					
800	0.002				0.0002	
1000		0.002			0	0.002

Leblond et, al. Acta Metallurgica, 1984.

Phase transformation of selected points during welding

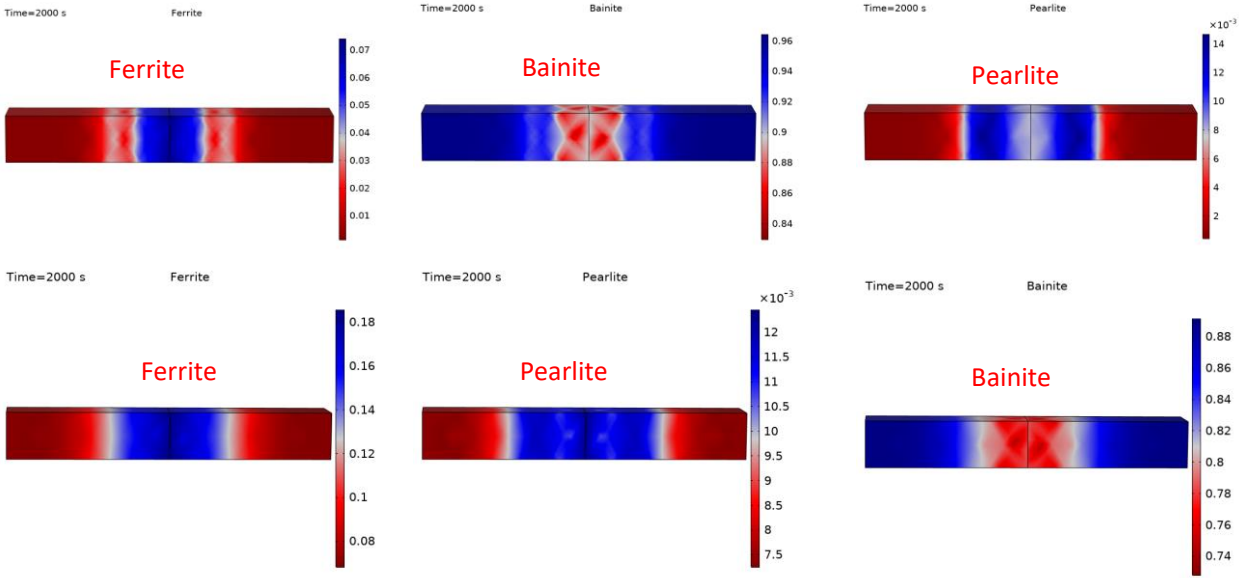






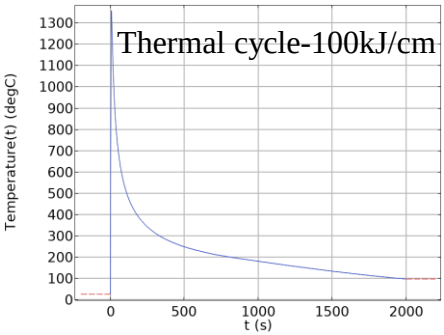
- The thermal cycle and microstructural evolution curve in point A are achieved.
- The phase fraction of the microstructure of experiment and simulation are in a good agreement.

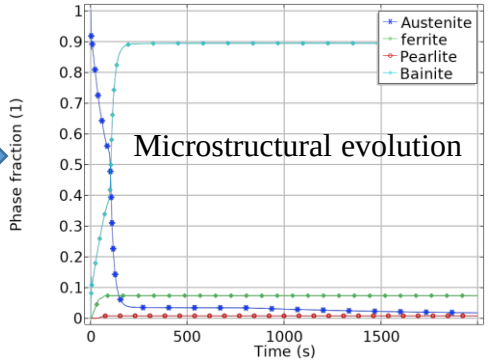
3-D cloud picture of microstructural evolution for Gleeble experiments

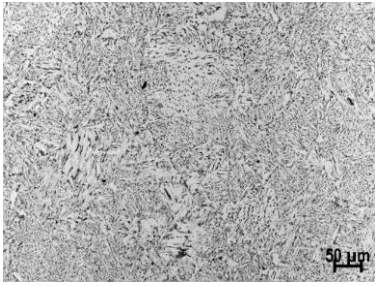


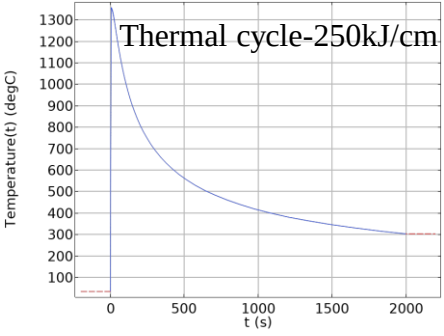
- Based on the validated Leblond-Devaux equation, the microstructural evolution are achieved
- The fraction of ferrite, bainite and pearlite are showing in the 3D diagram

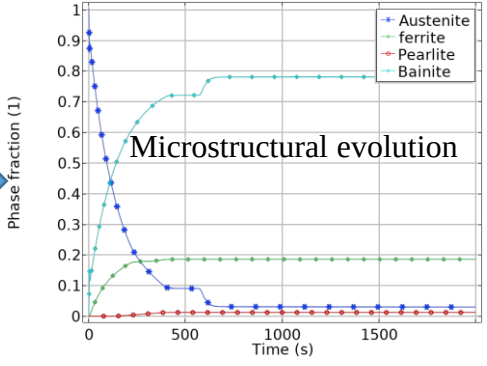
Phase transformation of selected points during welding

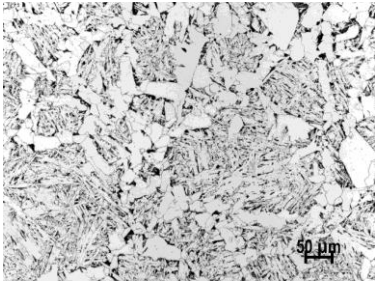












- The phase fraction of the microstructure of experiment and simulation are in a good agreement.

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Summary & Future work

- Thermal profile, and phase fraction of ferrite, bainite and pearlite transformation during the simulated welding process can be predicted by the model.

- Impact toughness of coarse grain zone of E36Nb is better than E36 with heat input 50kJ/cm, 100kJ/cm, 150kJ/cm, 200kJ/cm and 250kJ/cm.

- Addition of Nb-0.12%:
  - Expands the bainite transformation range of SHCCT
  - Reduces the content of proeutectoid ferrite and acicular ferrite
  - Increases the amount of granular bainite

- Leblond-Devaux parameters of $K_{s\rightarrow d}$ and $L_{s\rightarrow d}$ have been evaluated and simulated. SH-CCT diagram shows a good agreement with the experimental SH-CCT diagram.

- Develop the martensitic transformation model by Koistinen-Marburger equation.

Thanks for your attention!