INVERSE BAINITE FORMATION IN A Fe-5%Ni/Fe-10%Ni DIFFUSION COUPLE

EDUARDO FRANCO DE MONLEVADE
ARTHUR SEIJI NISHIKAWA
HÉLIO GOLDENSTEIN

LTF-Phase Transformations Laboratory
metalurgical and materials engineering dept.
Universidade de São Paulo
Escola Politécnica

Summary

- Introduction
- Experimental procedures
- Results
- Conclusions

INTRODUCTION

- Fe-Ni-C system: “well behaved” in morphological terms
- Not a strong carbide forming element – additional complications avoided
- High Ni alloys (9%Ni) are widely used in the oil & gas industry
- Lower Ni diffusion couples have been used before many times to study mechanisms of the ferrite precipitation reaction

INTRODUCTION

- An almost C-free diffusion couple was prepared, latter different C contents were added by thorough carburizing
- Low carbon (0.1% and 0.3% C) results were presented elsewhere; morphological transitions could be described only qualitatively
- Higher carbon (0.5% and 0.7%C) in this work showed the coexistence of lamellar and bainite products
- Inverse bainite was characterized in the 0.7%C

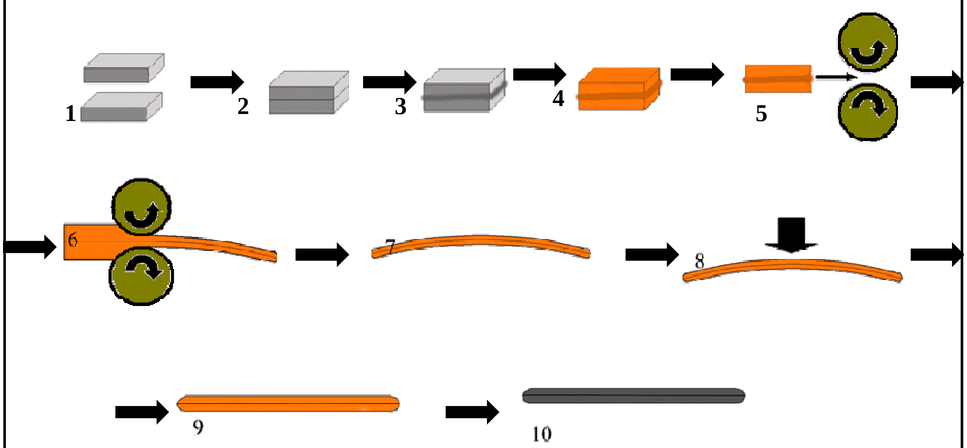
EXPERIMENTAL PROCEDURES

Composition of base alloys

Fe-Ni-5	***C***	***Ni***	***Si***	***Mn***	***Cr***	***Mo***	***W***	***V***
	0,010	*4,91*	*0,030*	*0,030*	*0,090*	*0,040*	*<0,010*	*<0,010*
	Ti	***Nb***	***Co***	***Cu***	***Al***	***P***	***S***	***N_2***
	<0,0050	*<0,010*	*0,010*	*0,050*	*<0,0050*	*<0,0050*	*0,001*	*0,0048*
Fe-Ni-10	***C***	***Ni***	***Si***	***Mn***	***Cr***	***Mo***	***W***	***V***
	0,003	*9,94*	*0,020*	*<0,010*	*0,090*	*0,040*	*0,030*	*<0,010*
	Ti	***Nb***	***Co***	***Cu***	***Al***	***P***	***S***	***N_2***
	<0,0050	*<0,010*	*0,010*	*0,050*	*<0,0500*	*<0,0050*	*0,001*	*0,0042*

Production of diffusion couples

Production of diffusion couples



Production of diffusion couples

Production of diffusion couples

- Diffusion treatments
  - 1350℃, 40 hours
- Cold rolling to extend the gradient
- New treatment at 1350℃ to eliminate heterogeneities

Production of the diffusion couples

- Carburation:
  - 0.5%C (McMaster University)
  - 0.7%C (HeatTech/Maxitrate)
  - There is a C gradient opposite to the Ni gradient due to effect of Ni on C activity
  - Chemical analysis (combustion) gave the following results:

  -for 0.5%C ->0.52%C for low Ni, 0.4%C for high Ni

  -for 0.7%C ->0.81%C for low Ni and 0.6% for high Ni

Heat Treatments

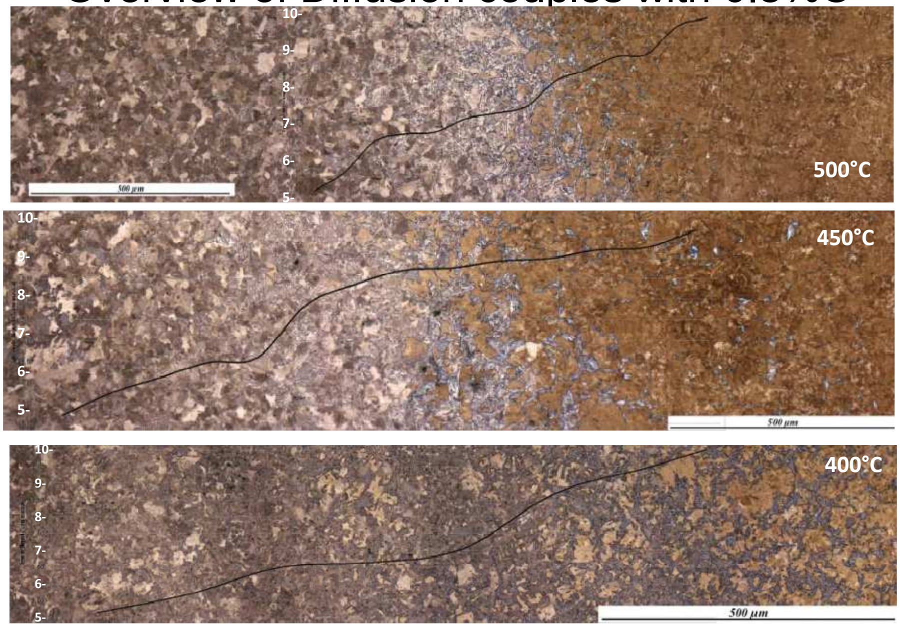
- Vacuum sealed quartz capsule with Ti chips to oxidyze preferentially
- Austenitizing – 900℃ – 20 minutes
- Capsule was broken inside the furnace

Heat Treatments

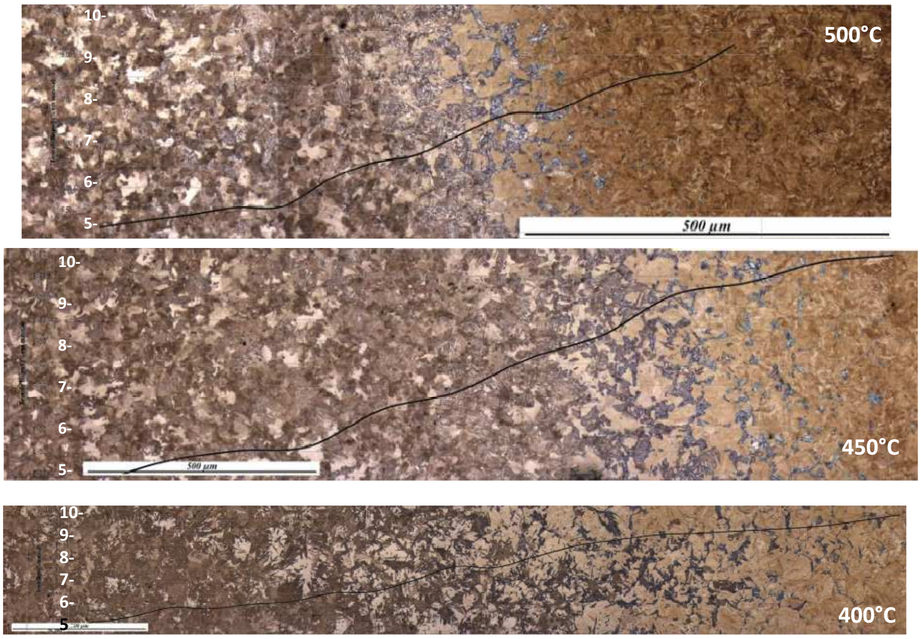
- Isothermal treatment in salt bath
  - 500℃, 10 minutes
  - 450℃, 10 minutes
  - 400℃, 10 minutes

RESULTS

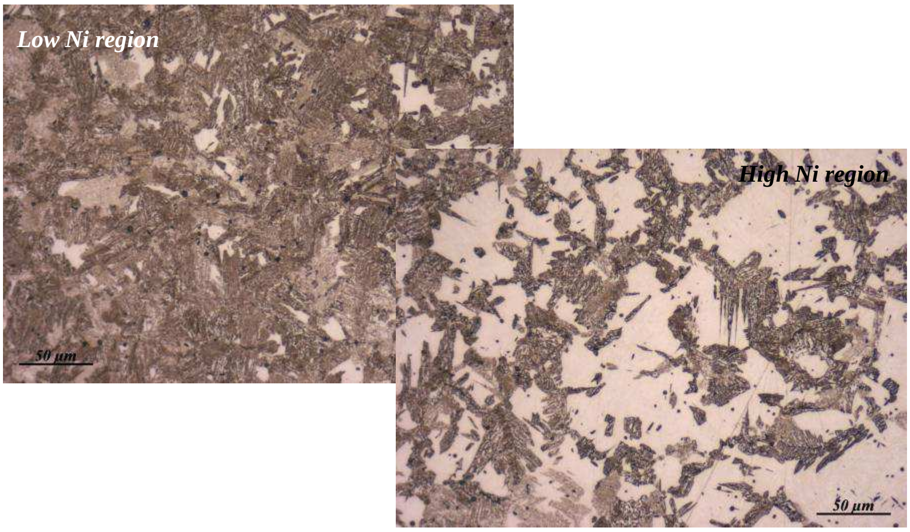
Overview of Diffusion couples with 0.5%C



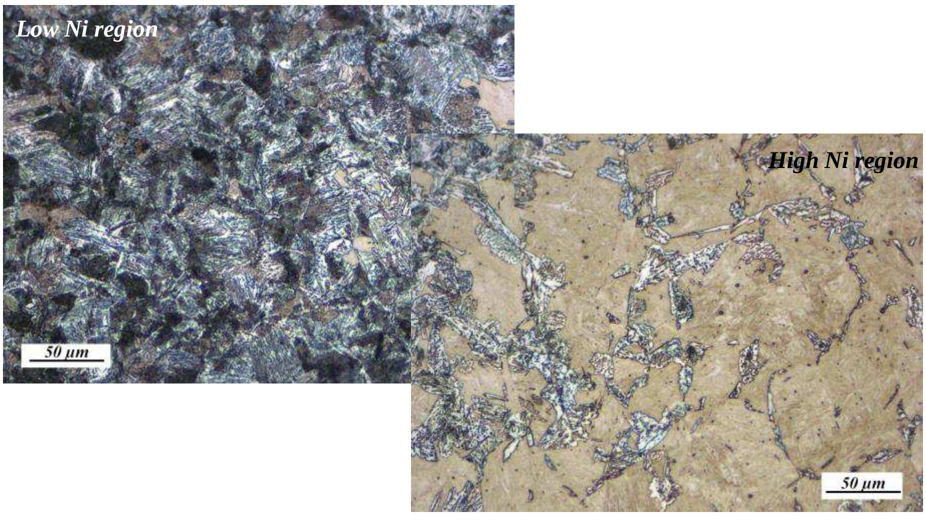
OVERVIEW OF DIFFUSION COUPLES WITH 0.7%C



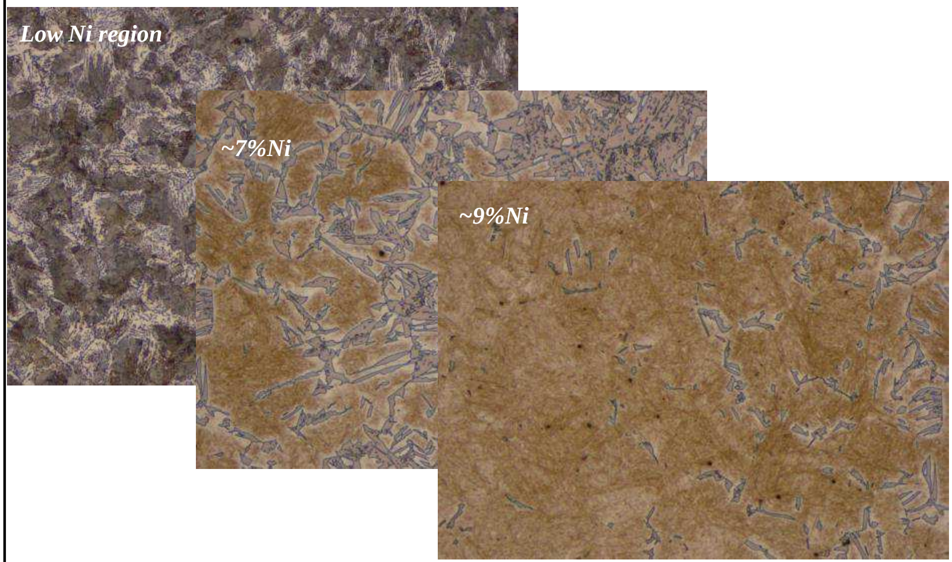
0,5%C – 400°C



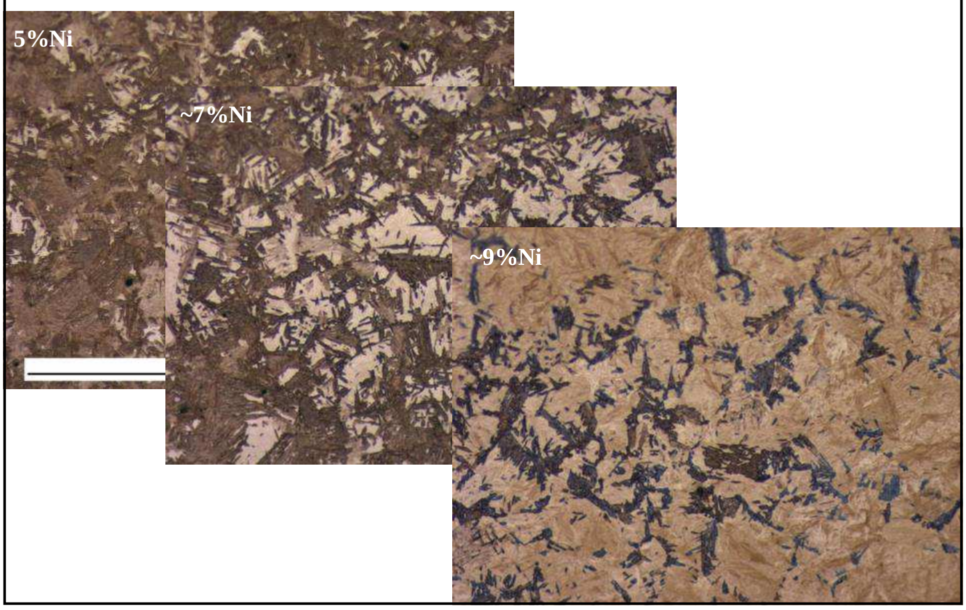
0.5%C – 450°C



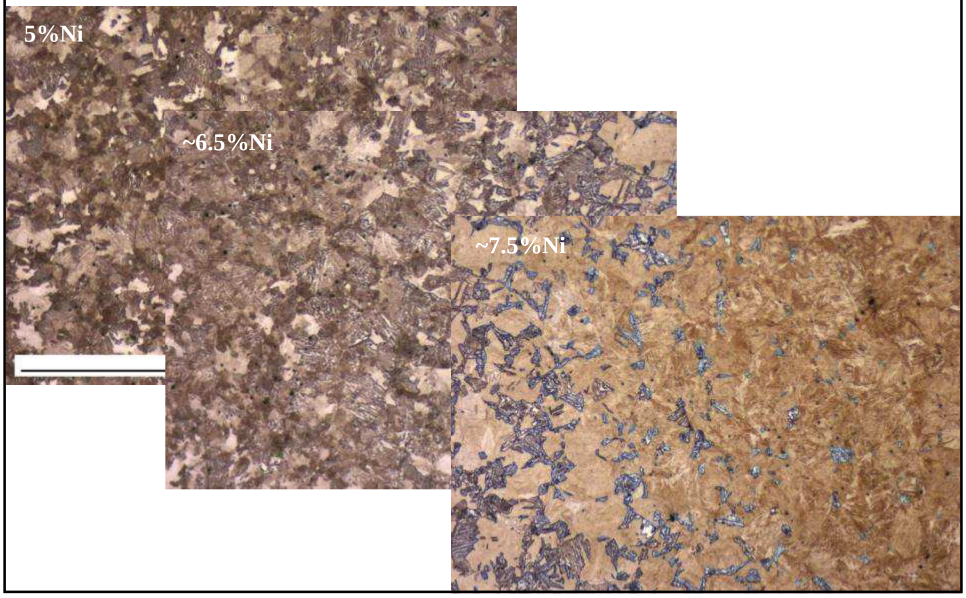
0.5%C – 500°C



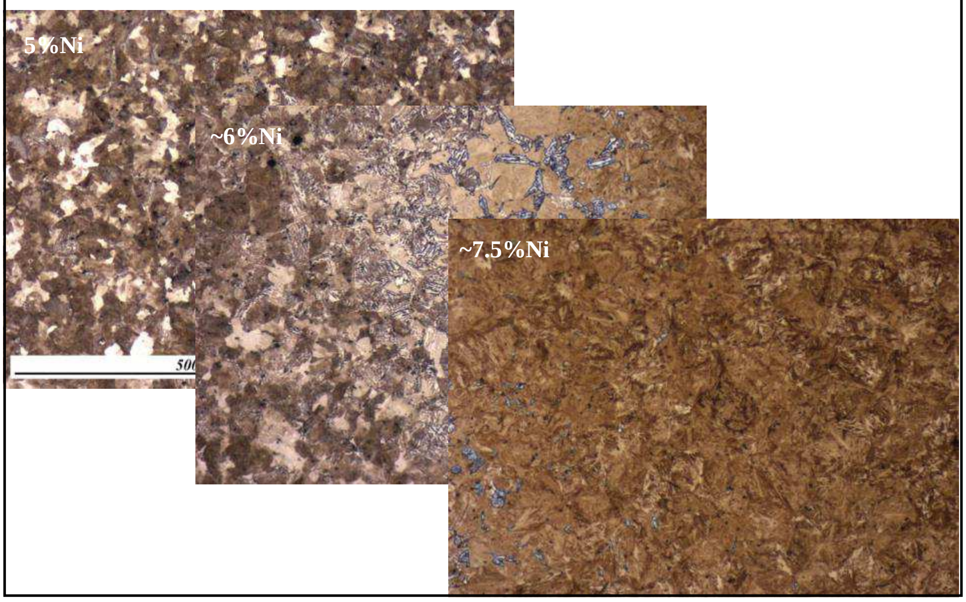
0.7%C – 400°C



0.7℃ – 450℃



0.7%C – 500℃



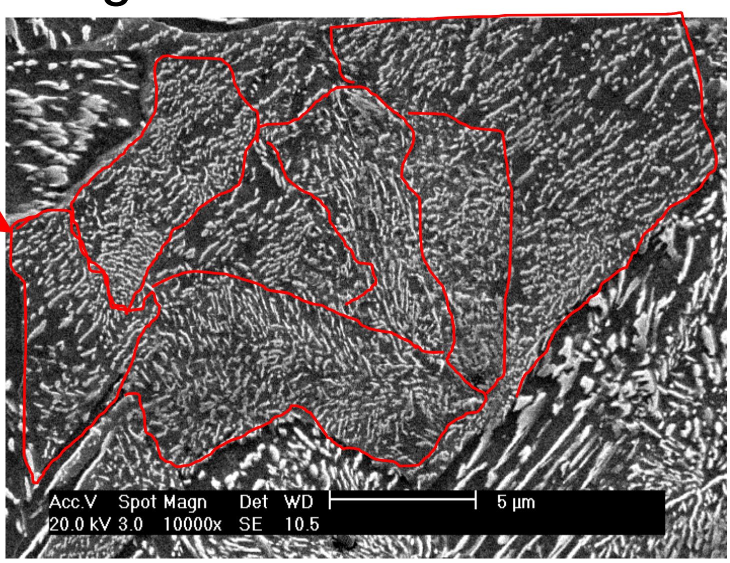
Degenerate Pearlite

- Described by Ohmori et al in 1971
- Originate from isothermal treatments at low temperatures (~450ºC), were sometimes interphase precipitation also occurs
- Cementite lamellae broken, continuous only for short distances
- Orientations change across pearlite nodule, suggesting the existence of pearlite sub grains
- Frequently found inside banded (segregated) regions of continuous cooled microalloyed steels

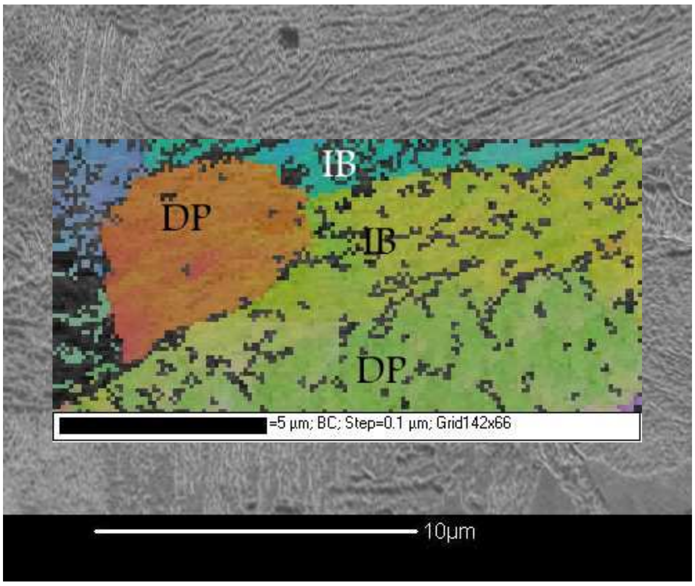
Degenerate Pearlite

Fragmented Lamellae

Sub-unit Structure



Couple carburized to 0.7%C - Sample treated at 450°C - 10 minutes
Low Ni Region



0.7%C
450°C
Low Nickel
Region

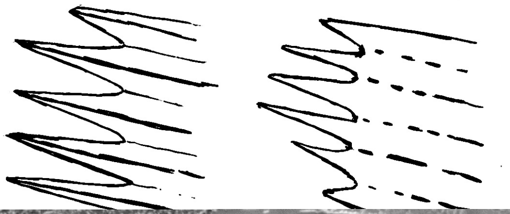
“Zero solution points” are due to carbides

Inverse Bainite

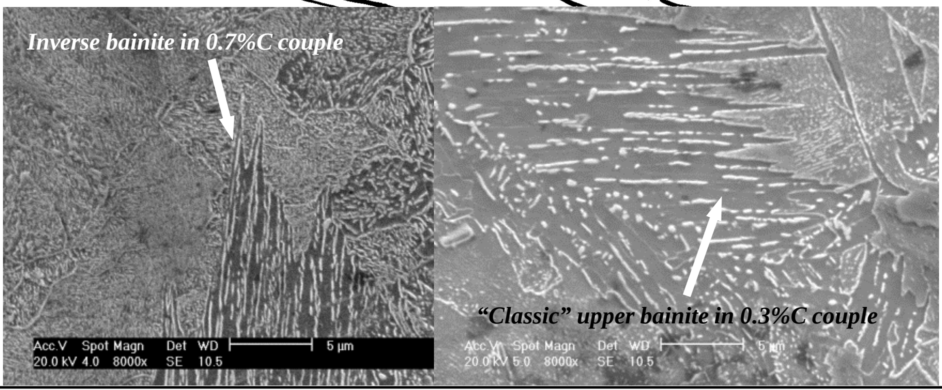
- Described by Hillert in 1957
- Growth led by cementite plates or needles
- Found in hypereutectoid alloys
- Indicative of symmetry of the phase diagram and of the austenite decomposition
- At 450℃ e 500℃, competes with degenerate pearlite in the 0.7% C diffusion couple
  - High Ni end of the diffusion couples has only martensite and a few IB plates, suggesting that Inverse Bainite nucleates before degenerate pearlite

Inverse bainite x Upper bainite

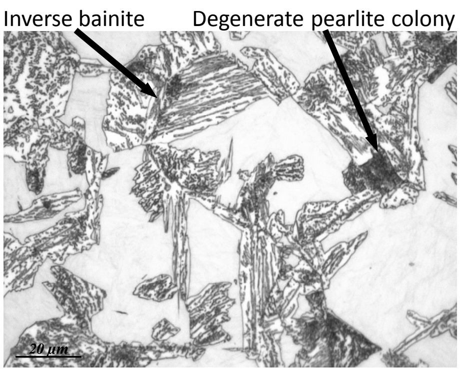
Inverse Bainite: Carbides in “spinal cord” position



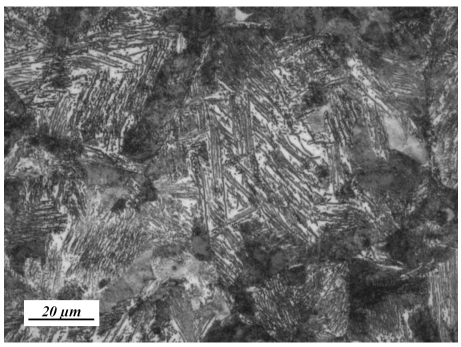
Upper Bainite: Carbides in the ferrite cusps



Inverse Bainite

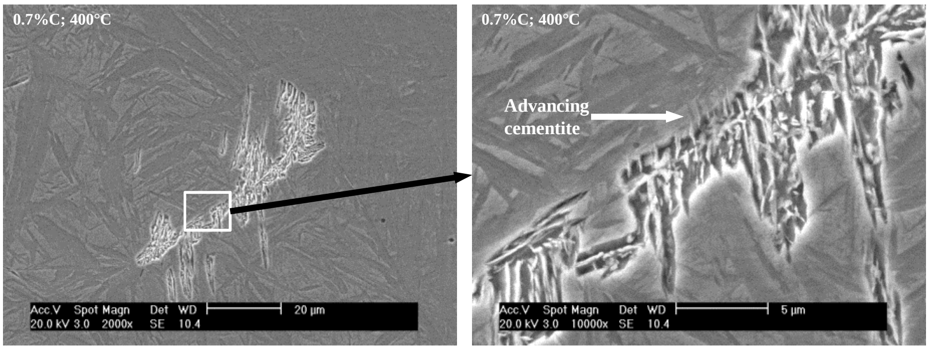


High Nickel region of the Diffusion couple:
The first product to be formed is inverse bainite; degenerate pearlite appears only afterwards
(0.7%C; 450℃)



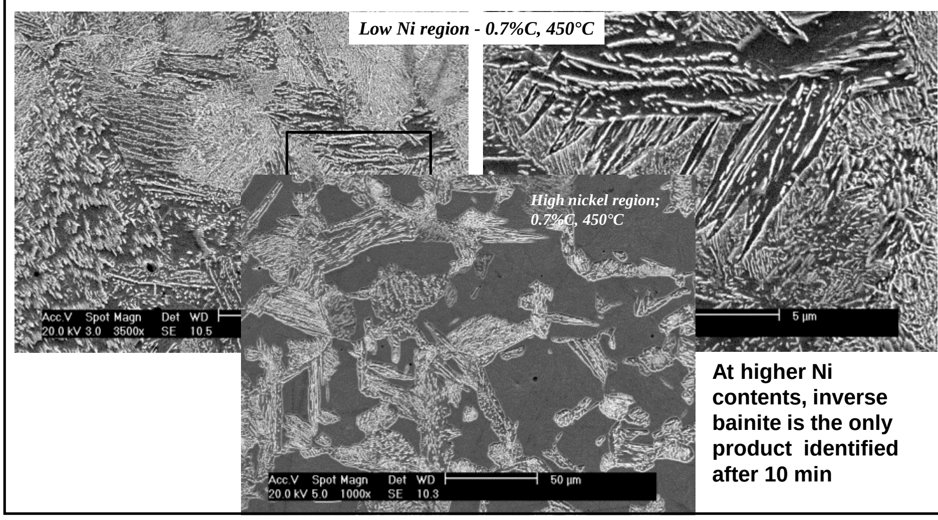
Low Nickel region of the Diffusion couple:
Degenerate pearlite competes extensively with inverse bainite
(0.7%C; 450℃)

Inverse Bainite



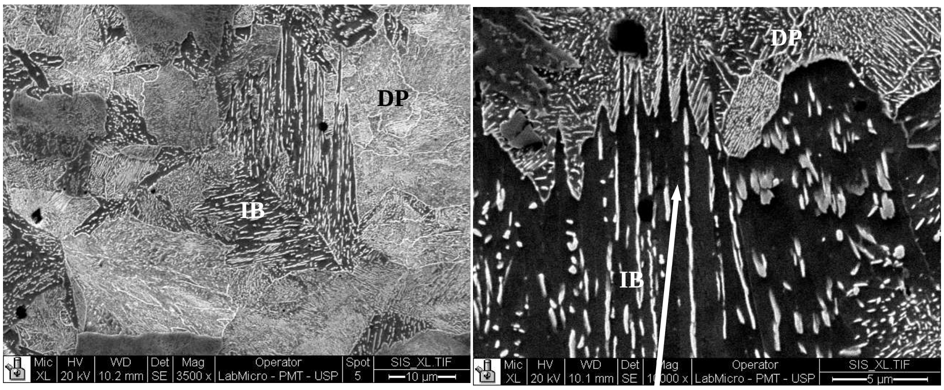
Cementite particles advancing into the previously untransformed austenite (later transformed to martensite upon quenching) indicate that cementite is the leading phase during eutectoid decomposition.

Inverse bainite x Degenerate Pearlite - 0.7%C



At higher Ni contents, inverse bainite is the only product identified after 10 min

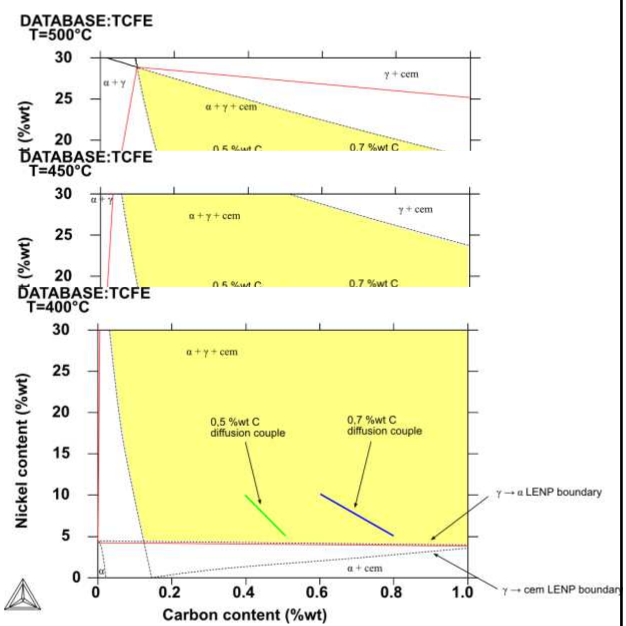
Upper Bainite or Inverse Bainite? - 0.5%C

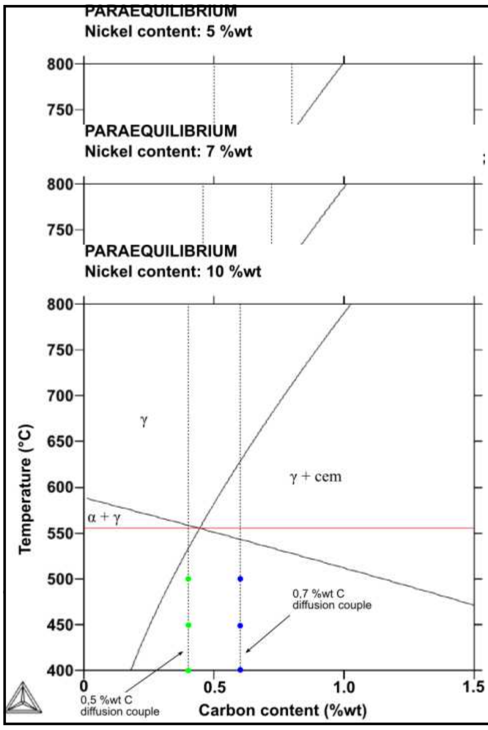


500℃ – 10 minutes;
Notice how the carbides are "spinal cords" to the bainitic ferrite

In all temperatures, the composition range of the diffusion couples lies outside the non-partition envelope for ferrite as well for cementite (yellow field). Thus, if the transformation occurs in conditions of local equilibrium, nickel diffusion in austenite must control the kinetics of transformation.
However, assuming that in the temperatures of the experiments the nickel mobility is too low, the local equilibrium regime is incompatible with the results.

Therefore, the transformation must necessarily occurs under paraequilibrium.





ThermoCalc calculations of the paraequilibrium diagrams suggest that the 0.5% C diffusion couple is slightly hipoeutectoid while the 0.7% C is clearly hipereuctetoid
The nature of the bainite in the 0.5%C diffusion couple is not clear

Competition: Inverse bainite x Degenerate Pearlite

- The composition range of the 0.7% C diffusion couple lies outside the non partition envelope for ferrite as well as for cementite;
- Thus the transformation must necessarily occur as a paraequilibrium transformation
- The pearlite reaction may eventually offer the means for some partition, via diffusion along the incoherent gamma/eutectoid interface

CONCLUSIONS

- The eutectoid decomposition of austenite in 0.7%C samples at 400℃ yields only inverse bainite
- At higher temperatures, bainite competes with degenerate pearlite; this competition is observed in samples with 0.5%C at all temperatures tested and on samples with 0.7%C at 450℃ and 500℃.
- The observation of inverse bainite in high carbon samples is a evidence of the symmetry of austenite decomposition products proposed by Hillert and co-workers.

Next Experiment

- Decarburizing of the 0.7% C diffusion couple, in order to understand the normal bainite / inverse bainite transition, and verify the paraequilibrium diagram symmetry
- The decarburizing apparatus is ready (inspired on classic G. Purdy experiments)