

DIS RESEARCH PROJECT NO. 43

DIMENSIONAL GROWTH OF DUCTILE IRON CASTINGS DURING HEAT TREATMENT

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Five Different Heat Treatments

Subcritical Anneal

Full Anneal

Normalizing

Quench & Temper (450 HB)

Quench & Temper (300 HB)

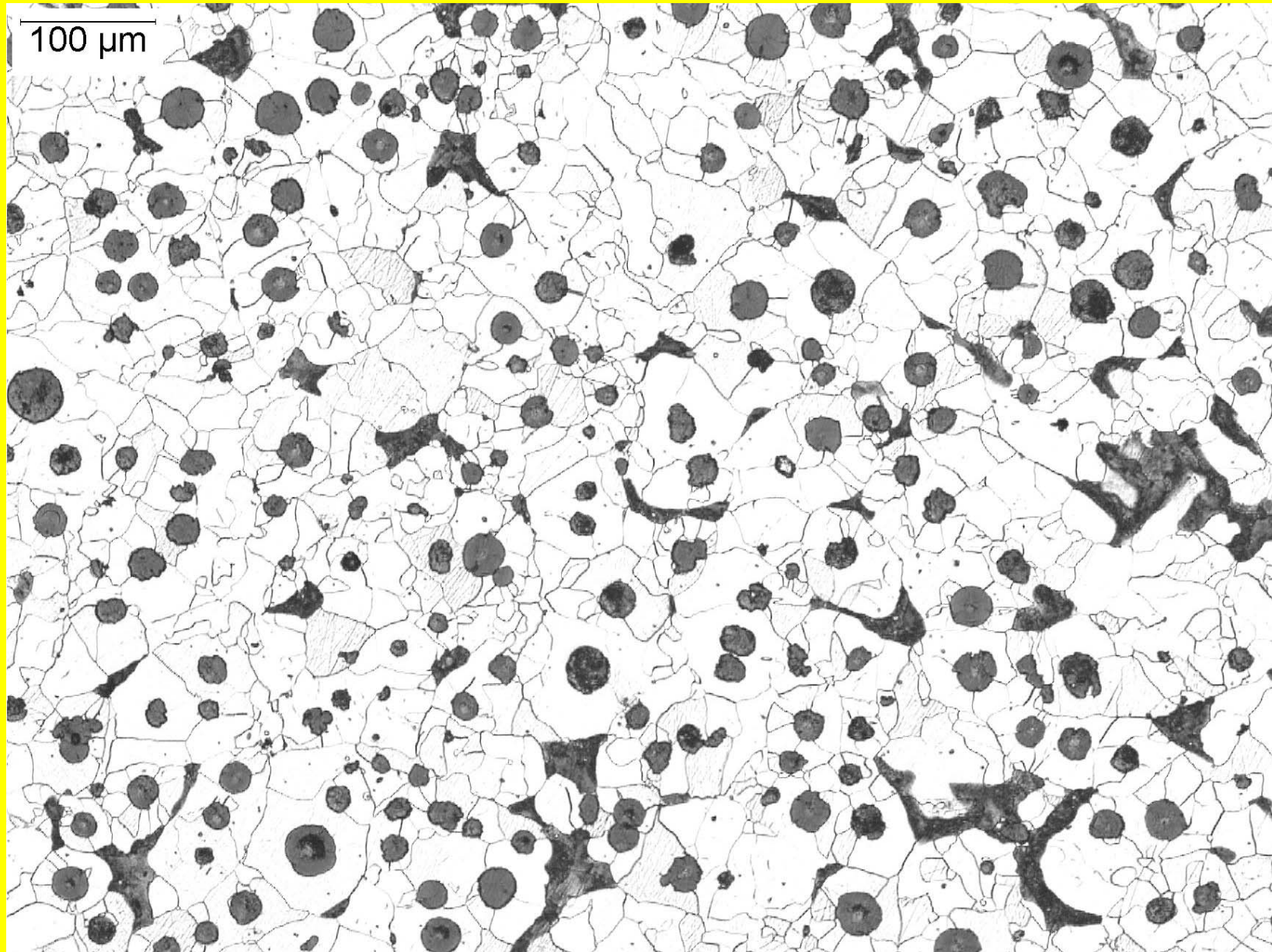
Three Grades of Ductile Iron

Ferritic D4512

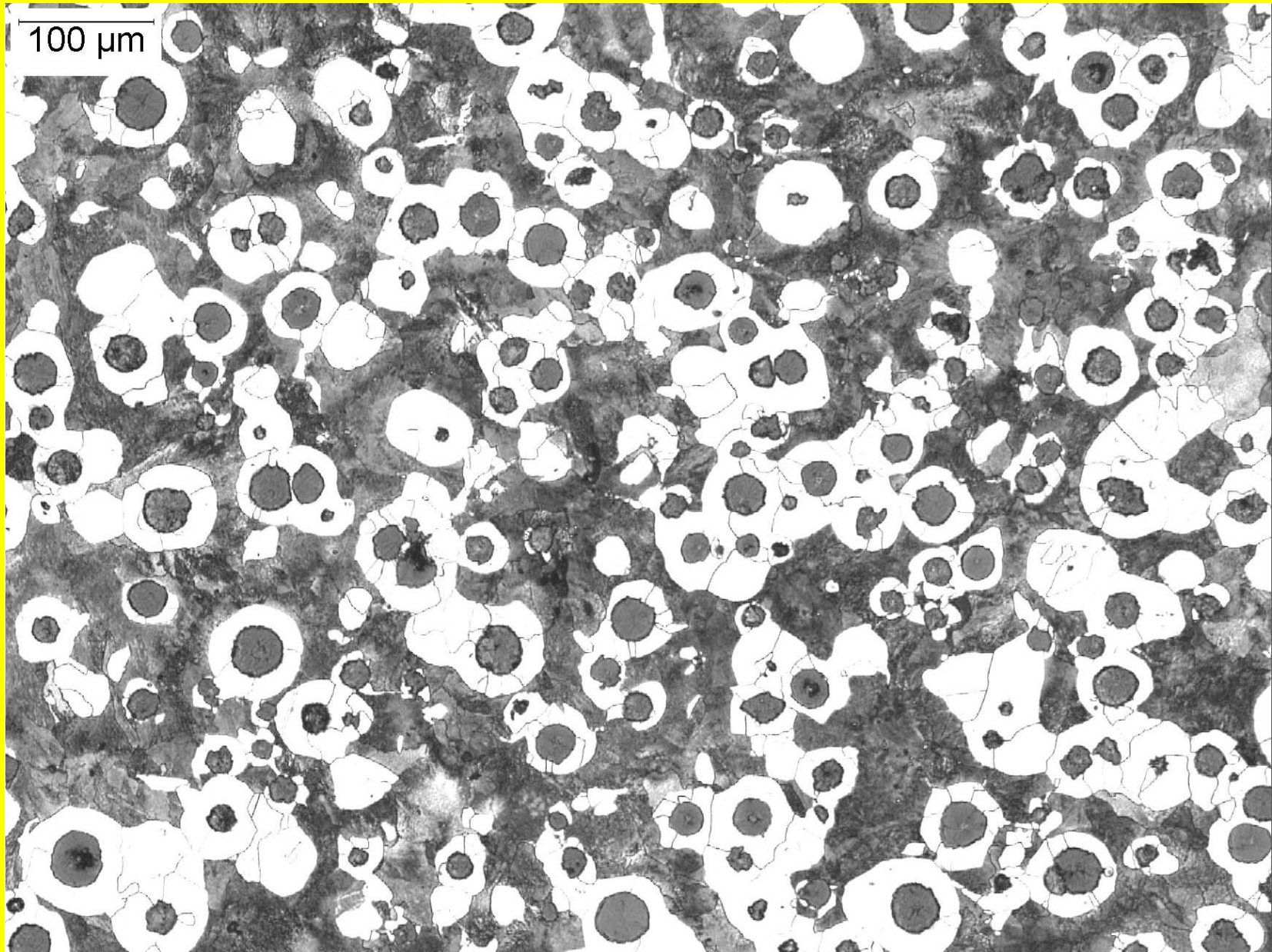
Ferritic-Pearlitic D5506

Pearlitic D7003

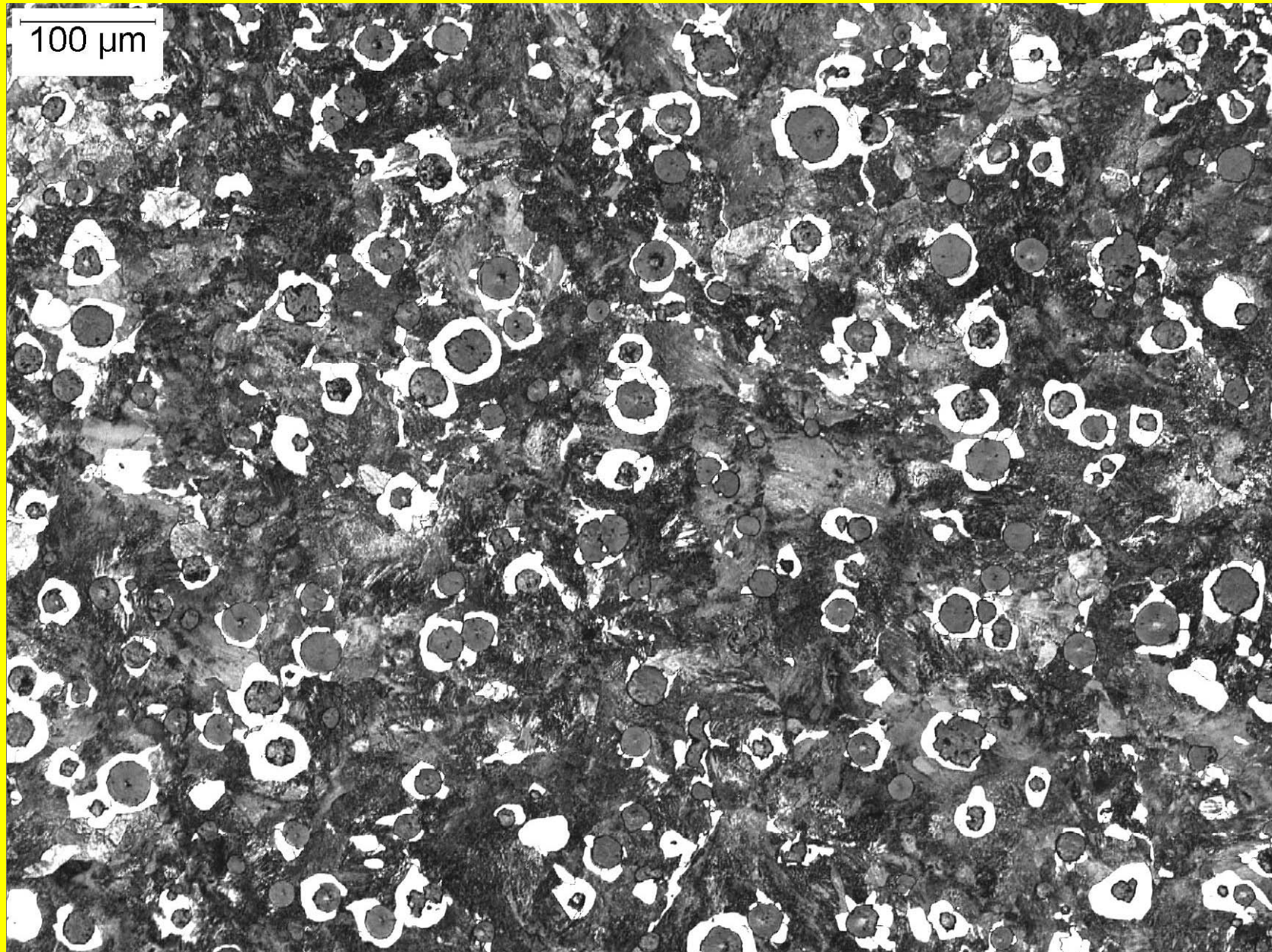
Ferritic D4512 ductile iron as-received



Ferritic-Pearlitic D5506 ductile iron as-received



Pearlitic D7003 ductile iron as-received



Materials and Test Matrix

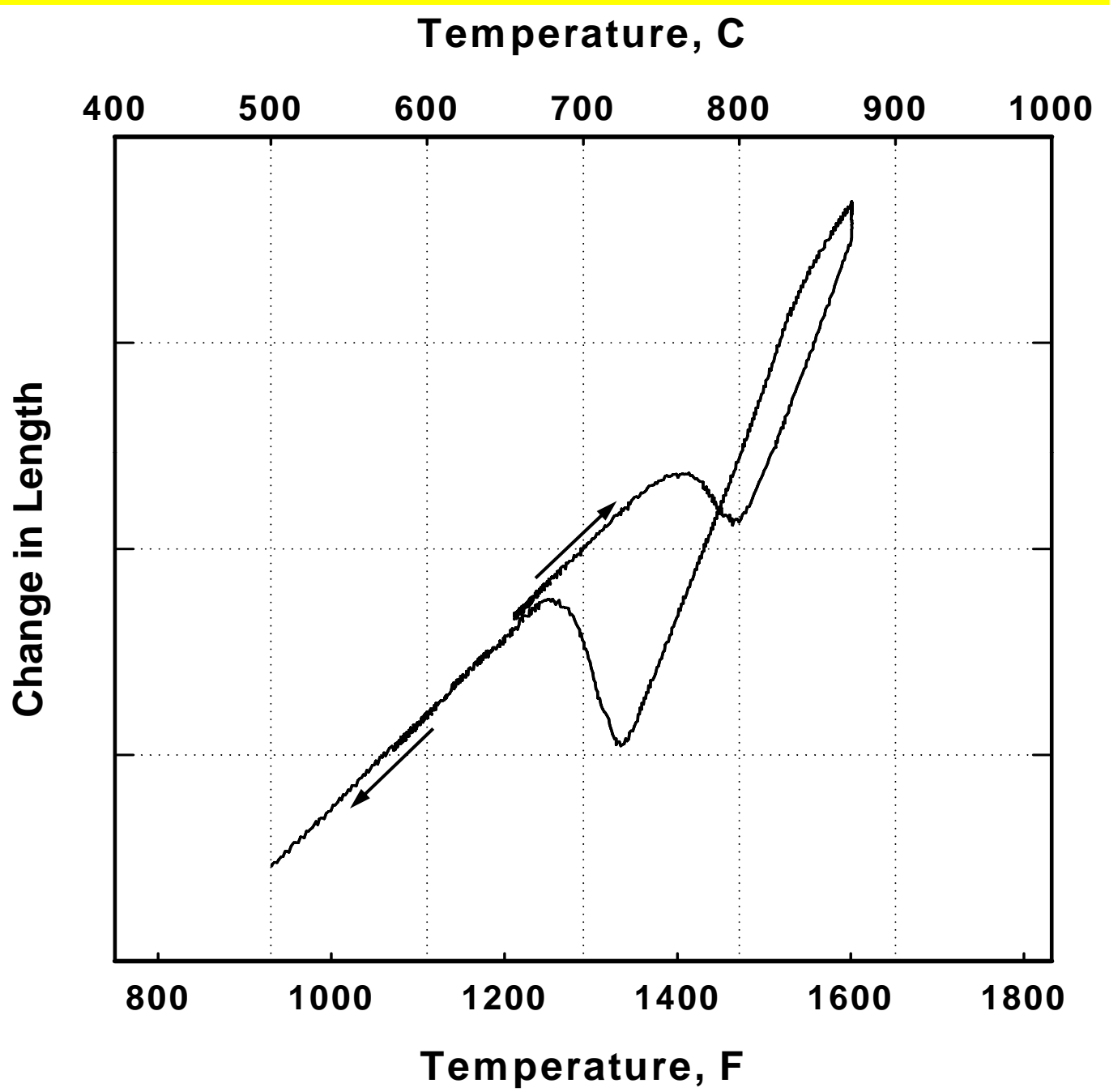
Grade / Heat-Treatment to be Evaluated	Initial Condition of Casting		
	Ferritic	F + P	Pearlitic
Ferritize Ann. Supercritical		X	X
Ferritize Ann. Subcritical		X	X
Normalize (Pearlitic)	X	X	
Q&T 450 HB	X	X	X
Q&T 300 HB	X	X	X

Heat-Treatment Parameters used in Study

Heat-Treatment	Heating Cycle		Soak Time	Cooling Rate
	Temperature	Time		
Full Anneal	872°C	1.5 h	1.5 h	3°C/min
Subcritical Anneal	718°C	1.5 h	1.5 h	3°C/min
Normalizing	900°C	1.5 h	1.5 h	Air
Quench & Temper (450 HB)	872°C	1.5 h	1.5 h	Oil
Quench & Temper (300 HB)	872°C	1.5 h	1.5 h	Oil

Method of Heat-Treatment

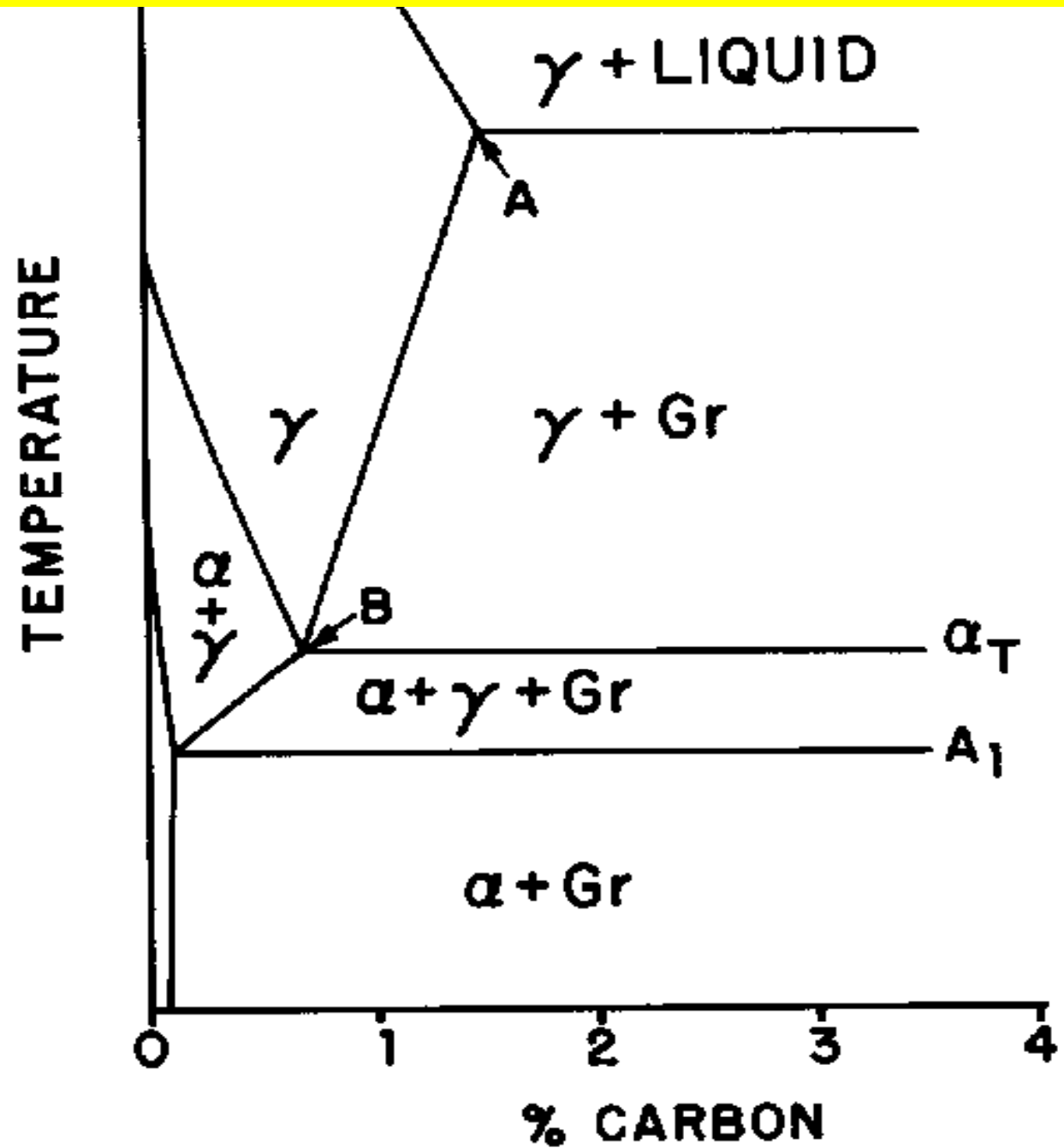
Heat-Treatment	Cooling Rate	Method
Full Anneal	3°C/min	Dilatometer
Subcritical Anneal	3°C/min	Dilatometer
Normalizing	Air	Lab Furnace
Quench & Temper (450 HB)	Oil	Lab Furnace
Quench & Temper (300 HB)	Oil	Lab Furnace



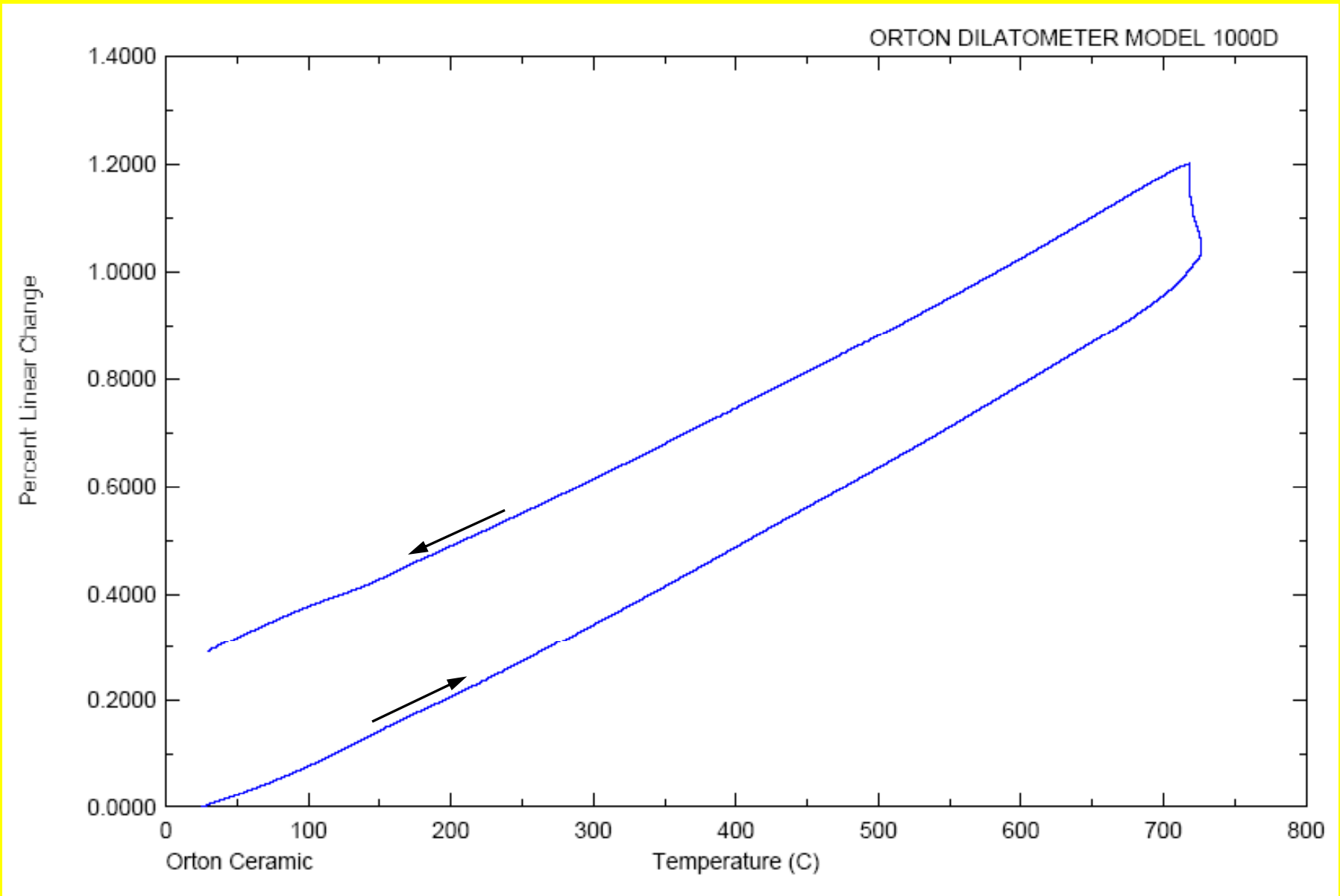
SOURCES OF GROWTH

- **Graphitization of Pearlite**
- **Recarburization of Austenite**
- **Irreversible growth due to Graphitization**
- **Martensite Formation**
- **Secondary Graphitization of Martensite**

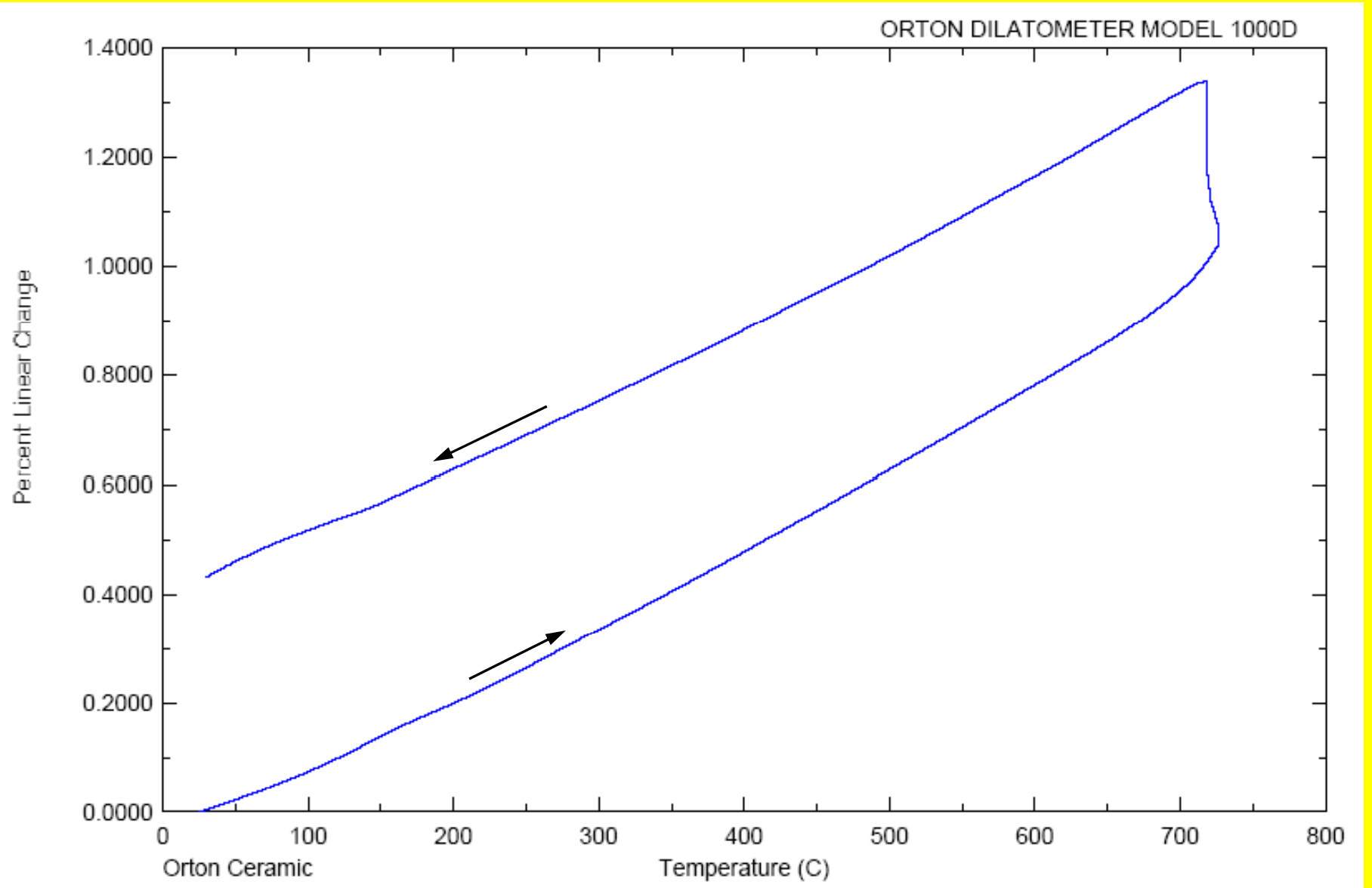
Fe-2%Si-C Diagram



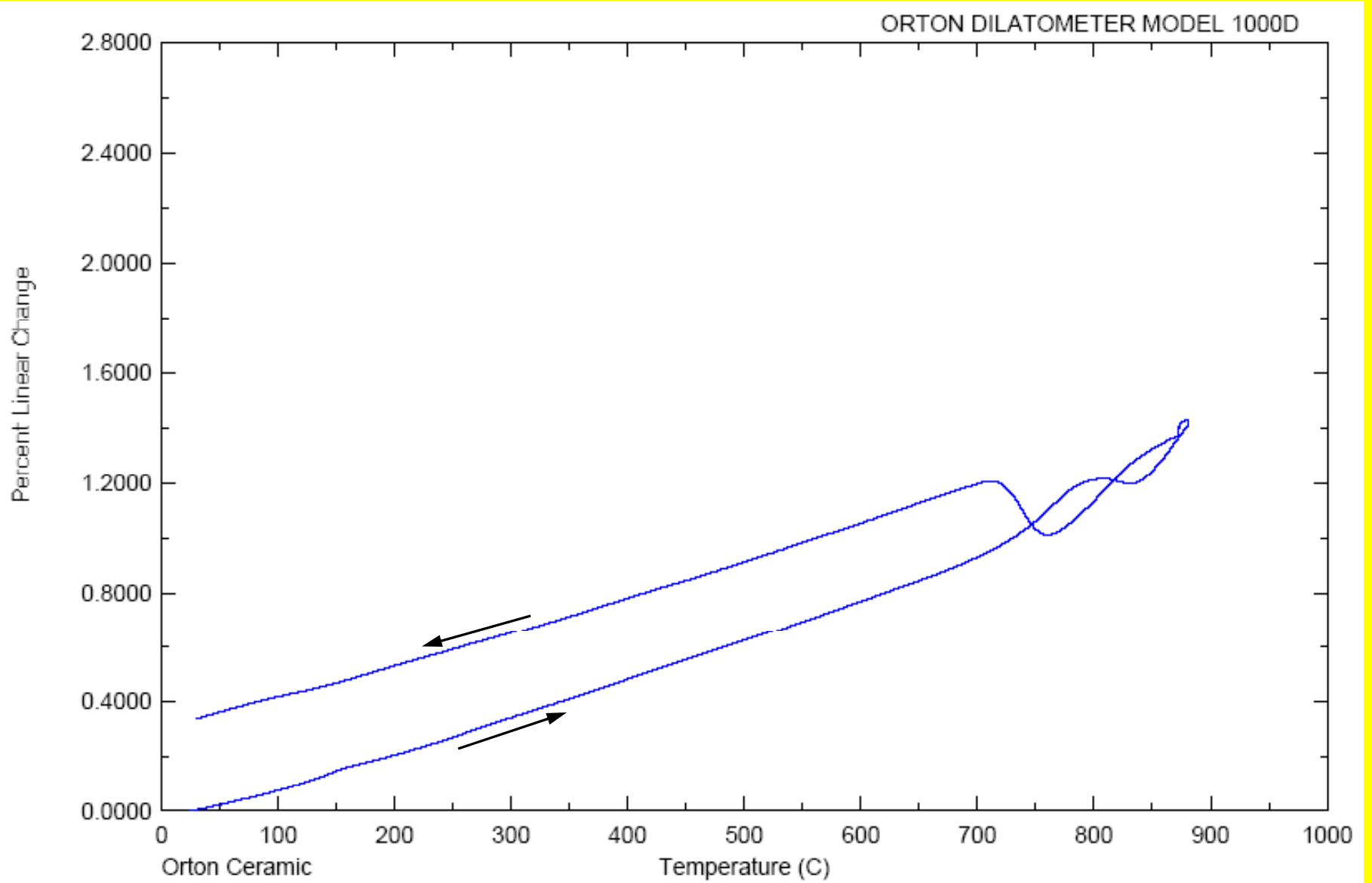
Grade D5506 in Subcritical Anneal Cycle



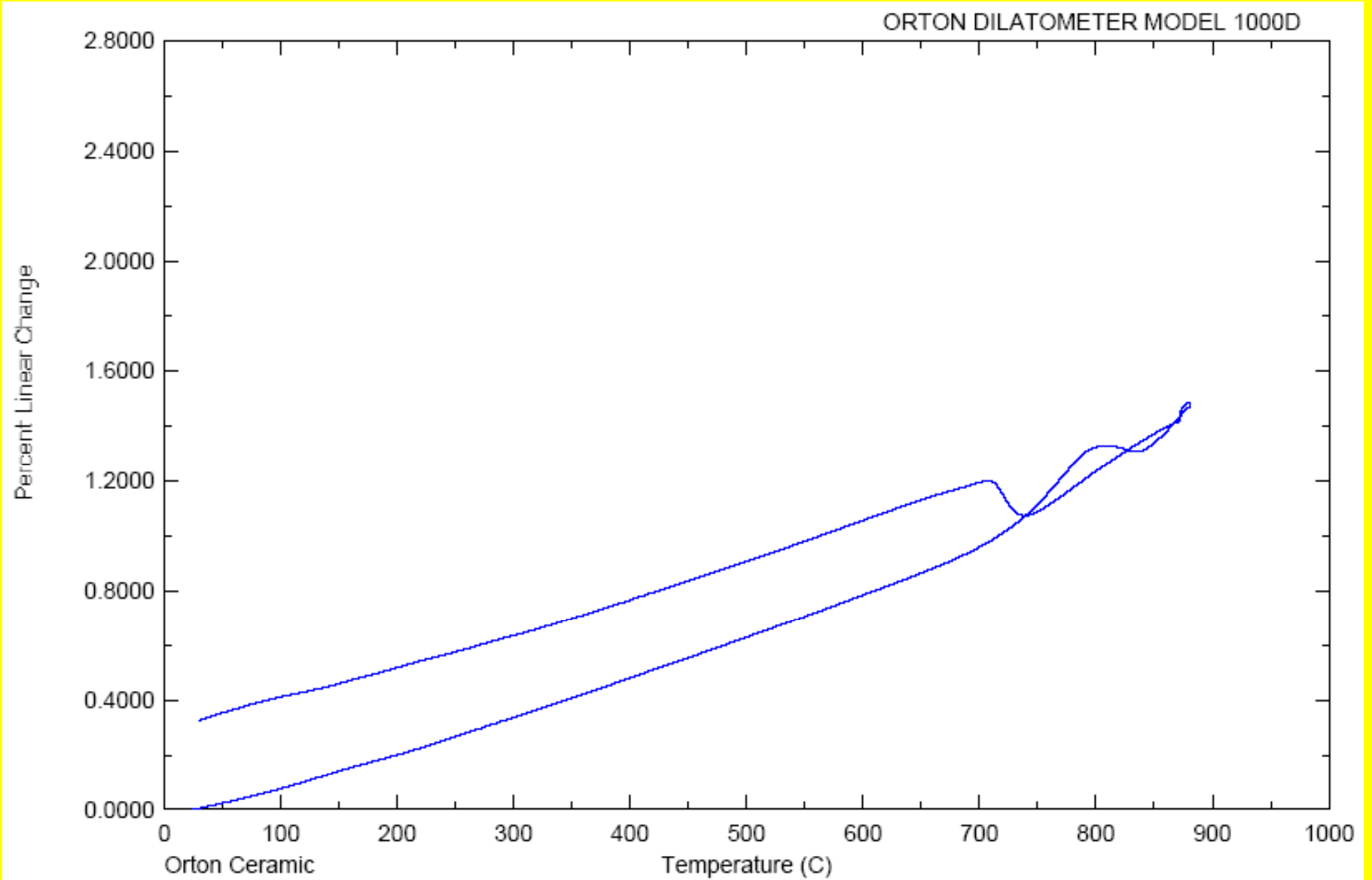
Grade D7003 in Subcritical Anneal Cycle



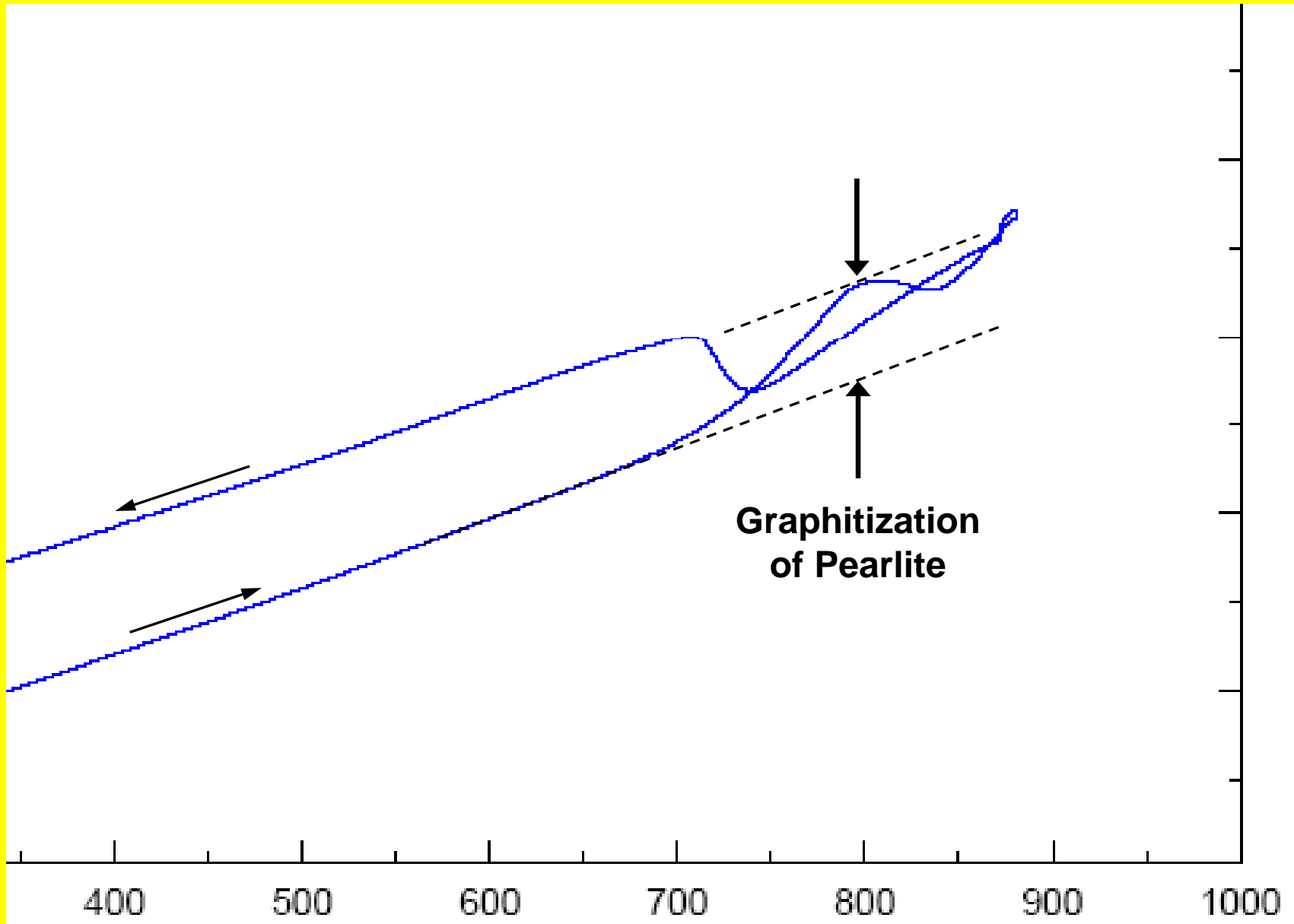
Grade D5506 in Full Anneal Cycle



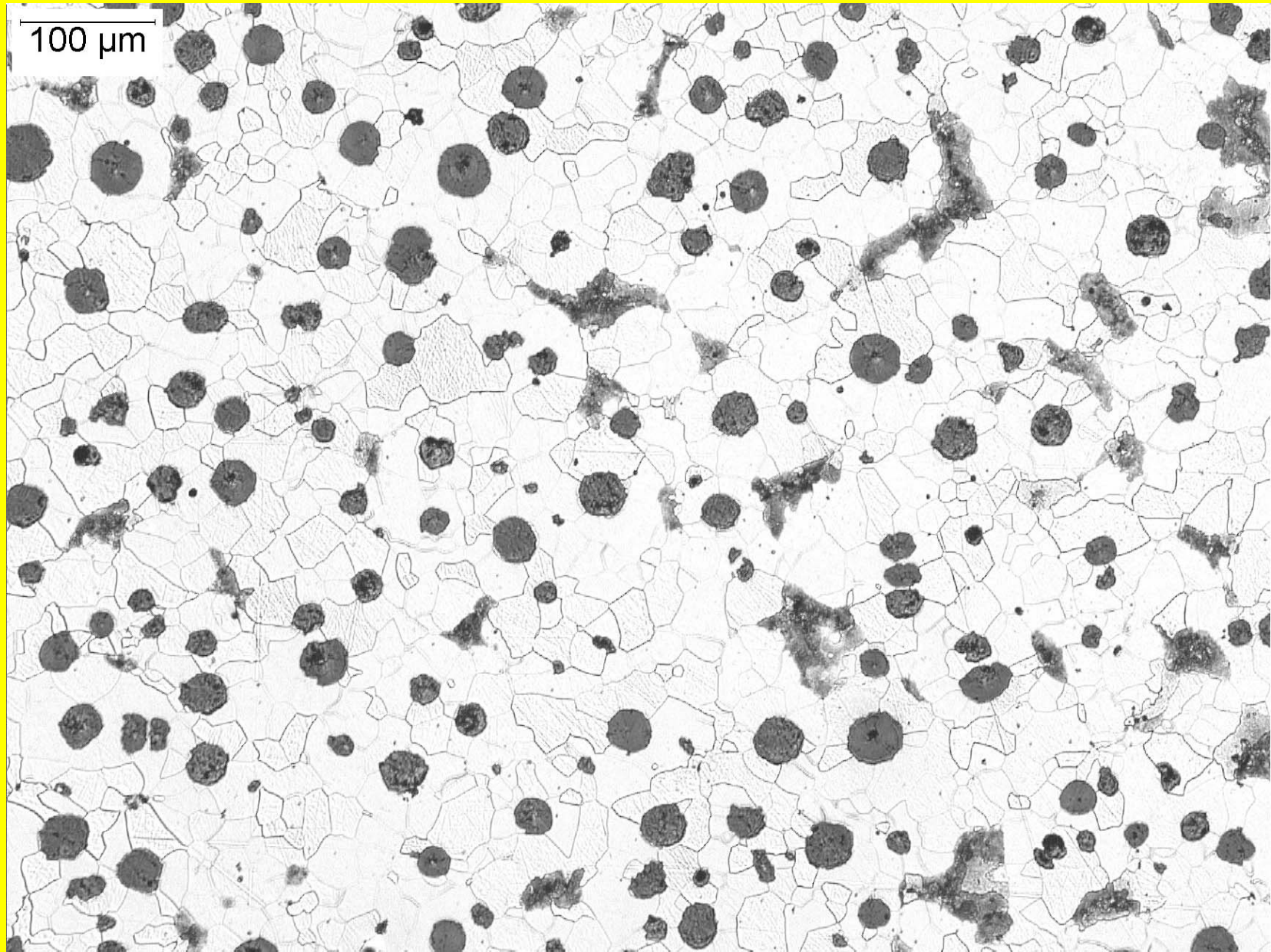
Grade D7003 in Full Anneal Cycle



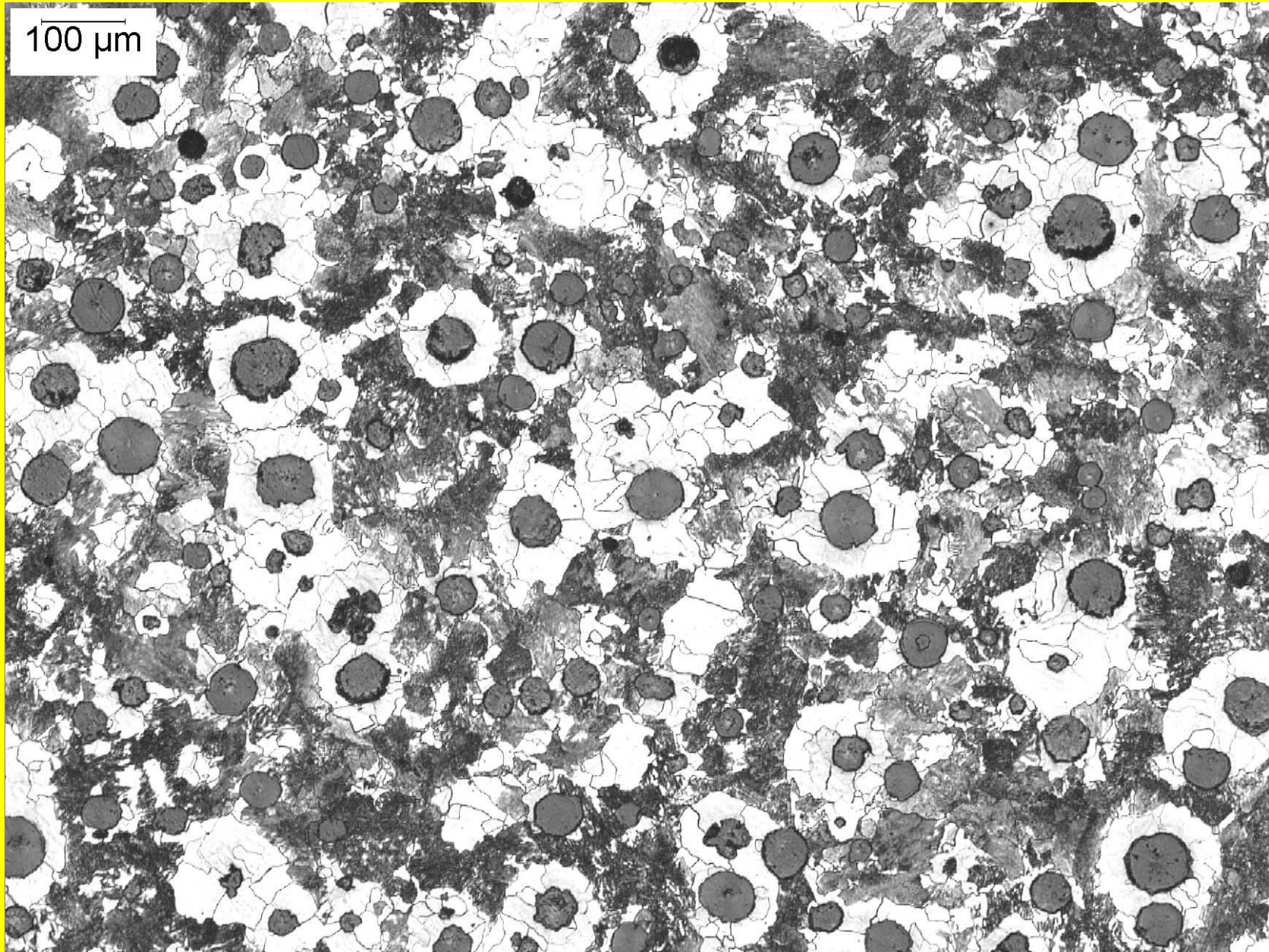
Grade D7003 in Full Anneal Cycle



Ferritic-Pearlitic D5506 ductile iron Full Anneal



Pearlitic D7003 ductile iron Full Anneal



Linear Growth Measurements in Three Ductile Iron Alloys

Sample ID	Condition	Temperature °F	Change in Length, %	Change in Length, in/in
100A	Quench & Temper	1600/950	0.122	0.0012 in
80A	Quench & Temper	1600/950	0.207	0.0021 in
65A	Quench & Temper	1600/950	0.080	0.0008 in
100B	Quench & Temper	1600/1100	0.142	0.0014 in
80B	Quench & Temper	1600/1100	0.178	0.0018 in
65B	Quench & Temper	1600/1100	0.134	0.0013 in
80C	Normalized	1650	0.177	0.0018 in
65C	Normalized	1650	0.068	0.0007 in
100A	Subcritical Ann	1325/4h	0.430	0.0043 in
80A	Subcritical Ann	1325/4h	0.288	0.0029 in
100B	Full Anneal	1600/1.5h	0.323	0.0032 in
80B	Full Anneal	1600/1.5h	0.333	0.0033 in

Sources of Growth

In Subcritical Annealing:

- Graphitization of Pearlite**

In Supercritical Annealing:

- Decomposition of Pearlite on heating**
- Carburization of Austenite**
- Re-formation of graphite on cooling**

Sources of Growth

In Normalizing:

- Decomposition of Pearlite on heating
(influenced by rate of heating)
- Carburization of Austenite

In Quench & Temper:

- Decomposition of Pearlite on heating
- Carburization of Austenite
- Formation of low-density Martensite
- Secondary graphitization

Graphitization of Pearlite

In Subcritical Annealing:

0.43% Growth in D7703

0.29% Growth in D5506

In Supercritical Annealing:

0.32% Growth in D7703

0.33% Growth in D5506

In Normalizing (on heating to A_1):

0.177% Growth in D5506

0.068% Growth in D4512

Conclusions

1. All five heat treatments resulted in growth in all three grades of ductile iron.
2. The starting microstructure influences the amount of growth that occurs, whether annealing, normalizing, or quenching and tempering.
3. The primary cause for growth is attributed to graphitization of pearlite. Pearlite is more dense than the graphite + ferrite replacing the pearlite.
4. One unexpected source of growth occurred -- pearlite decomposed on heating to the lower critical temperature.
5. Additional graphitization occurred on tempering, when martensite decomposed. More growth occurred at the higher tempering temperature.
6. A total of five reactions were identified as contributing to the growth of ductile iron parts during heat treatment. They include; decomposition or graphitization of pearlite, recarburization of austenite, secondary graphitization of martensite, irreversible growth during graphitization, and martensite formation.

Acknowledgement

The test bars received from Neenah Foundry for this study are gratefully acknowledged.