Project # 42

Ultrasonic Velocity Testing of Nodularity Coupons

Principal Investigators

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Current Methods for Checking Nodularity

- Fracture / Bend / Ring
- Resonant Frequency
- Mg / S Cup
- Ultrasonic
- Cut / Polish / Micro
  - ASTM Microlug
  - In the Mold Sample
  - Immersion Sample
  - Pour on Top of Mold

Ultrasonic Velocity Testing

1. Can Ultrasonic Velocity be Used to Verify Nodularity for Process Control

2. What's the Influence of Common Foundry Variables on Velocity Measurement

Ultrasonic Velocity Testing

Samples

½” Rectangular in Shell Mold (ACP)

¾” Square in Shell Mold (Quality Castings)

Metal Types

Regular Ductile Iron

High Silicon Moly

Cooling Conditions

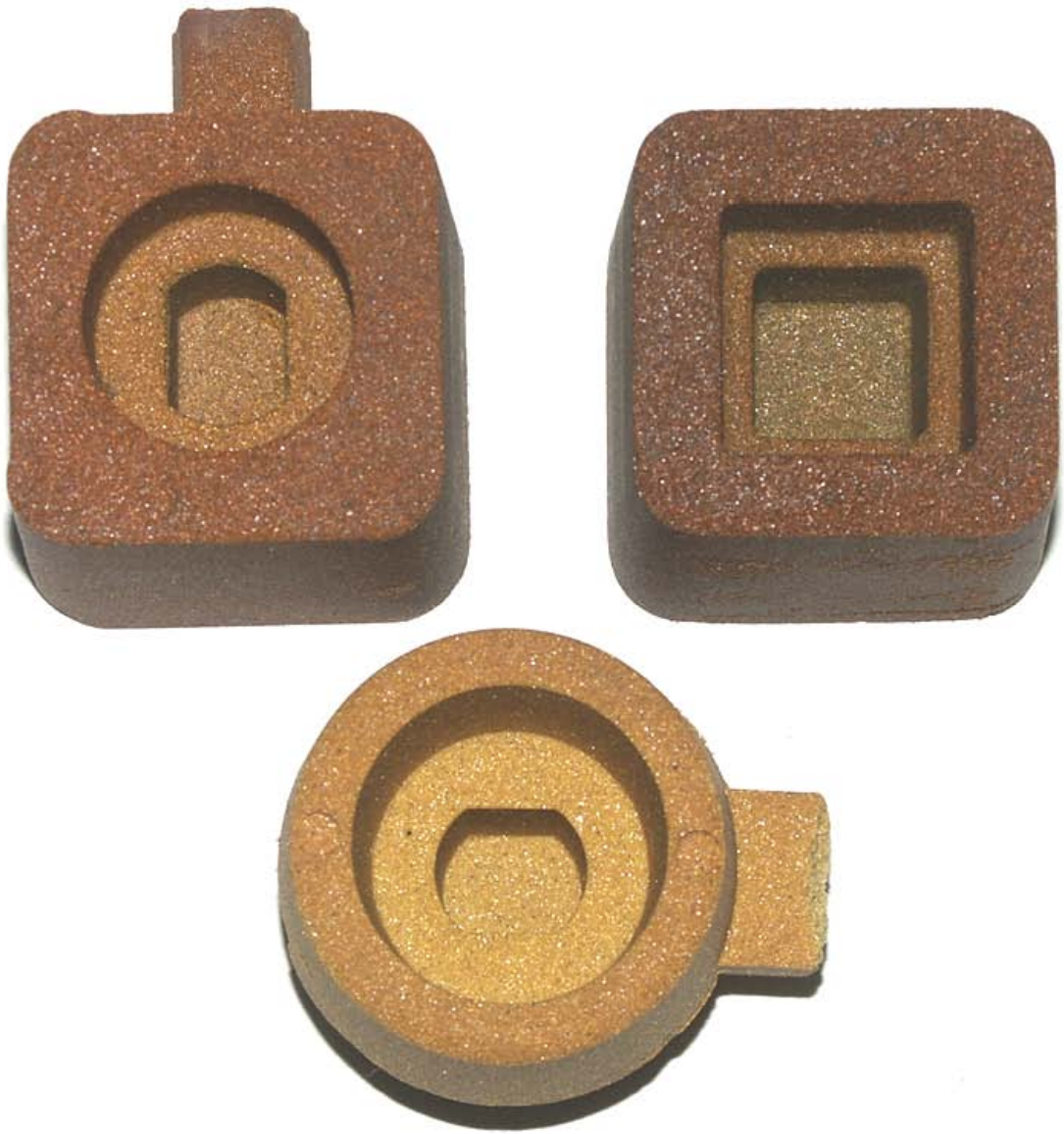
Mold Cool

Air Cool

Water Quench

Foundry Participation

ACP
Neenah
Quality Castings
Citation - Lufkin
Grede - New Castle
Wescast - Wingham



Nodularity and UT Velocity Measurement in Ductile Iron

- Nodularity lugs from six foundries
- Efforts made to evaluate influence of:
  - Degenerate graphite
  - Metallic matrix - Quenching time
  - Carbides
- Nodularity rated by Image Analysis
- Measured UT Velocity
- Looked for Correlations

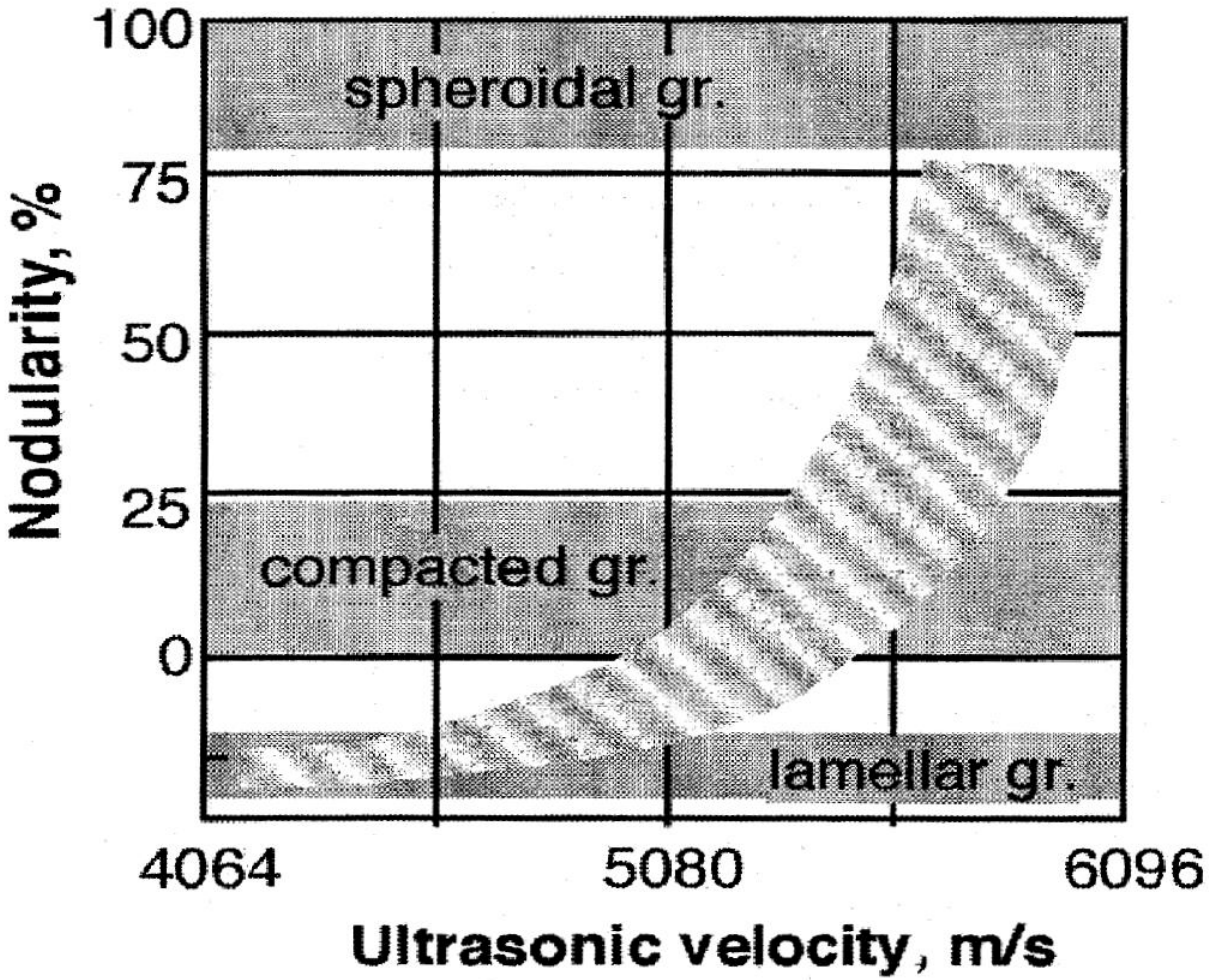
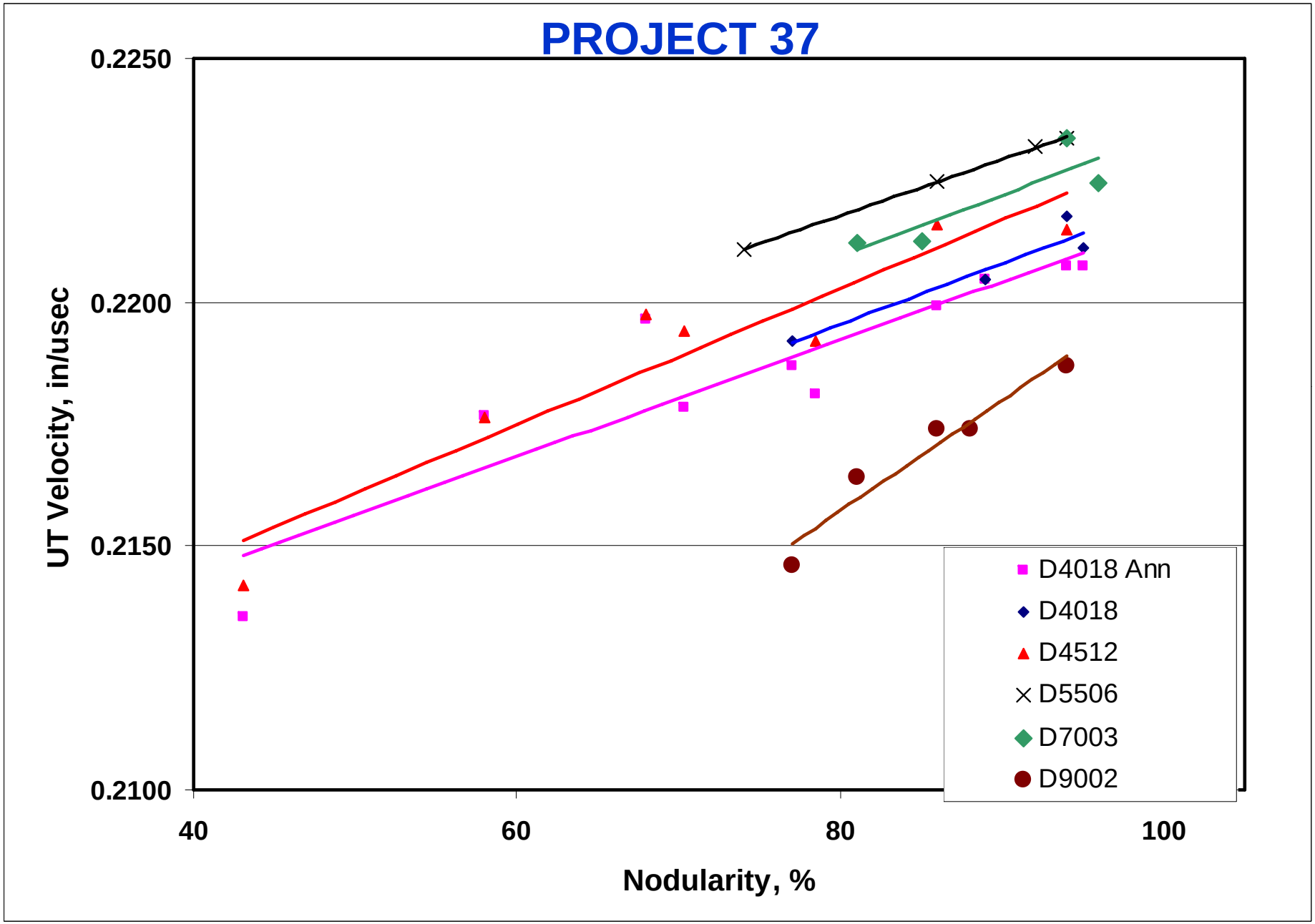


Fig. 8-35. Correlation between graphite shape and ultrasonic velocity.[72]

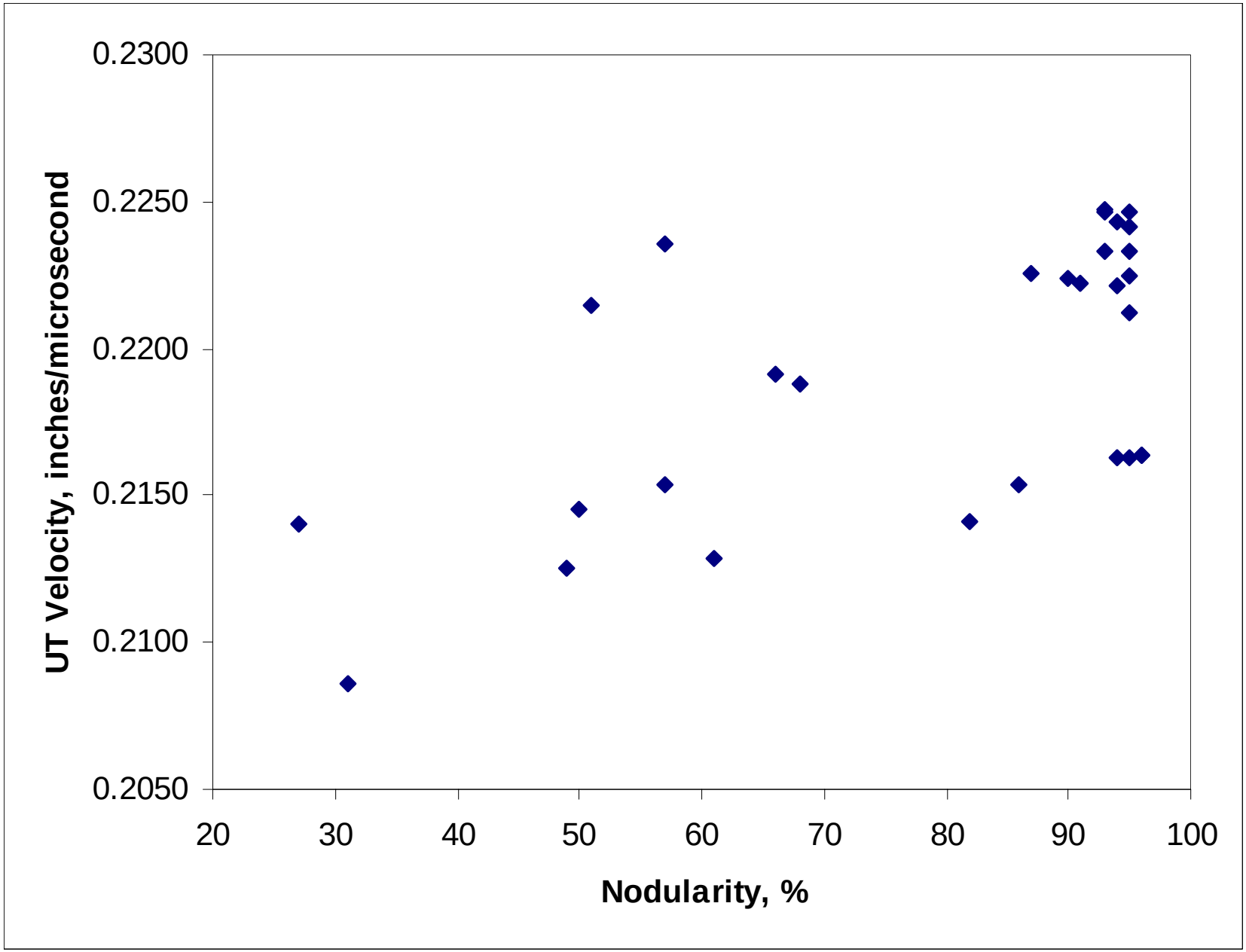

PROJECT 37
0.2250
0.2200
0.2150
0.2100
UT Velocity, in/usec
40
60
80
100
Nodularity, %
D4018 Ann
D4018
D4512
D5506
D7003
D9002

Ultrasonic Velocity
(Speed of Sound in DI)

- Graphite attenuates the velocity. The greater the interruption, the slower the speed.
- Interatomic bond strength (elastic modulus) of metallic matrix affects the speed of sound
- Density of matrix affects the speed of sound

Nodularity by Image Analysis

- Shape Criterion – Compactness of 0.7
- Nodularity by area fraction
- Particles under 10 microns excluded
- Analyzed 20-26 fields across sample

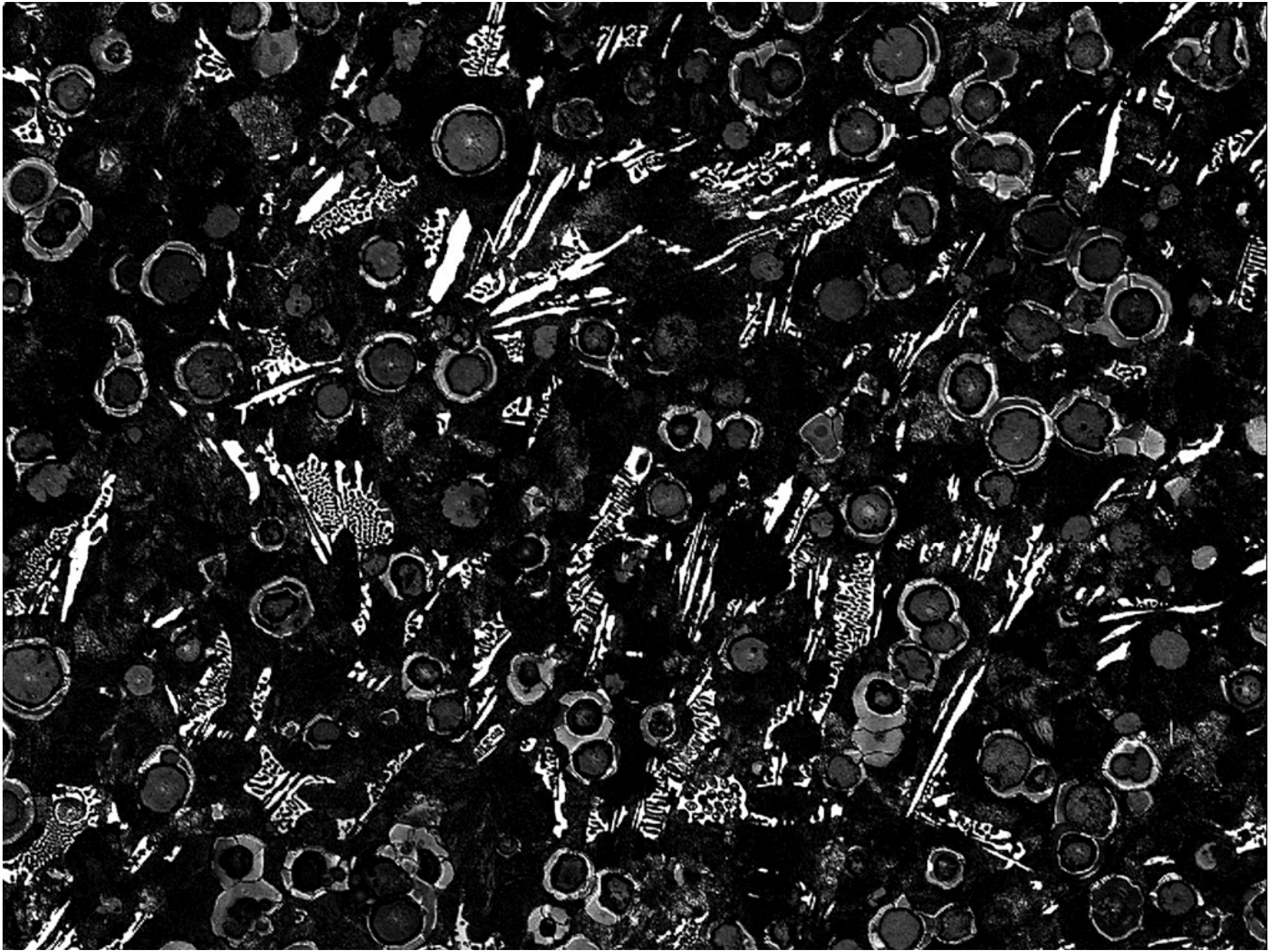

0.2300
0.2250
0.2200
0.2150
0.2100
0.2050
UT Velocity, inches/microsecond
20
30
40
50
60
70
80
90
100
Nodularity, %

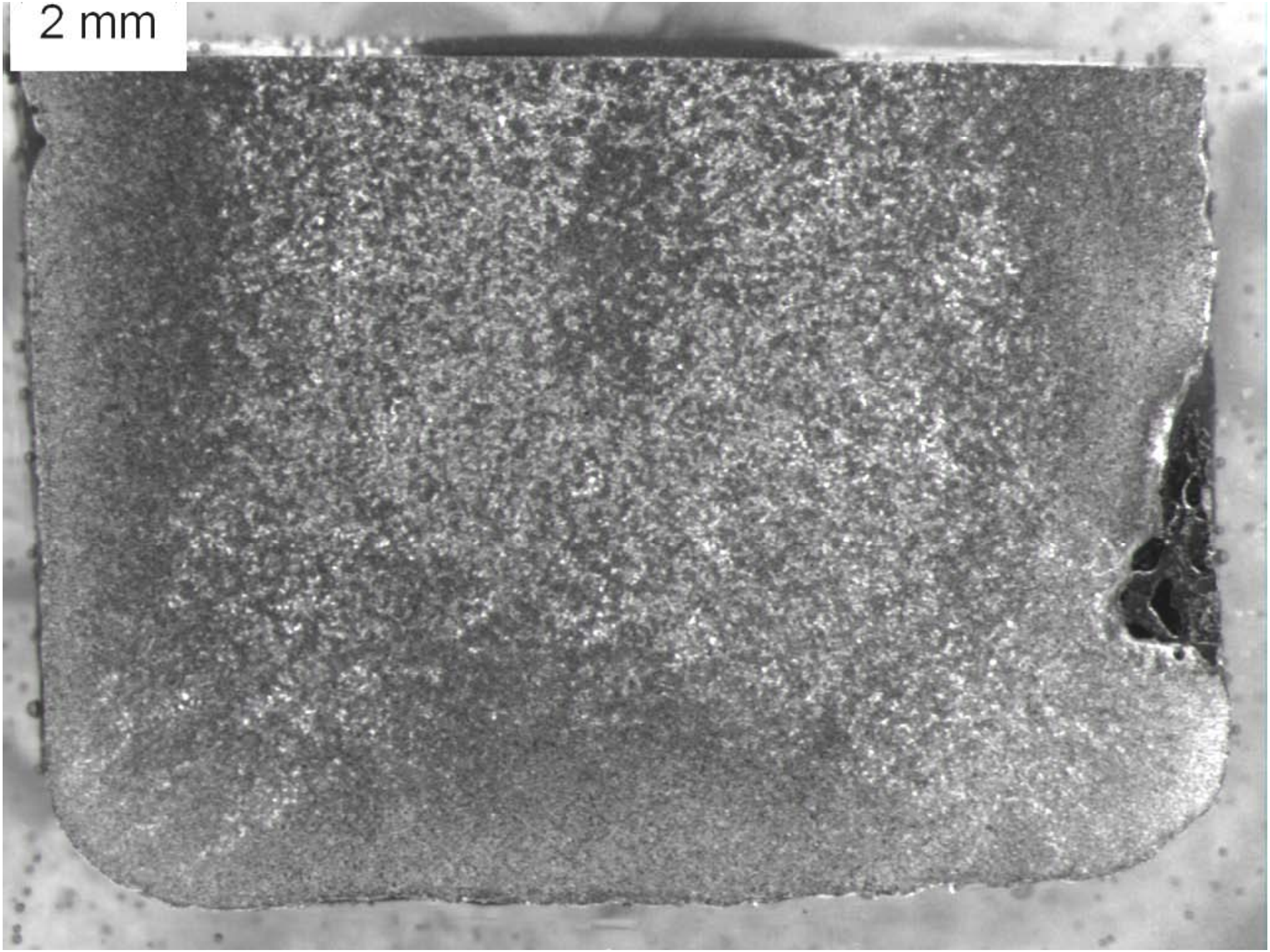
What Affects UT Velocity

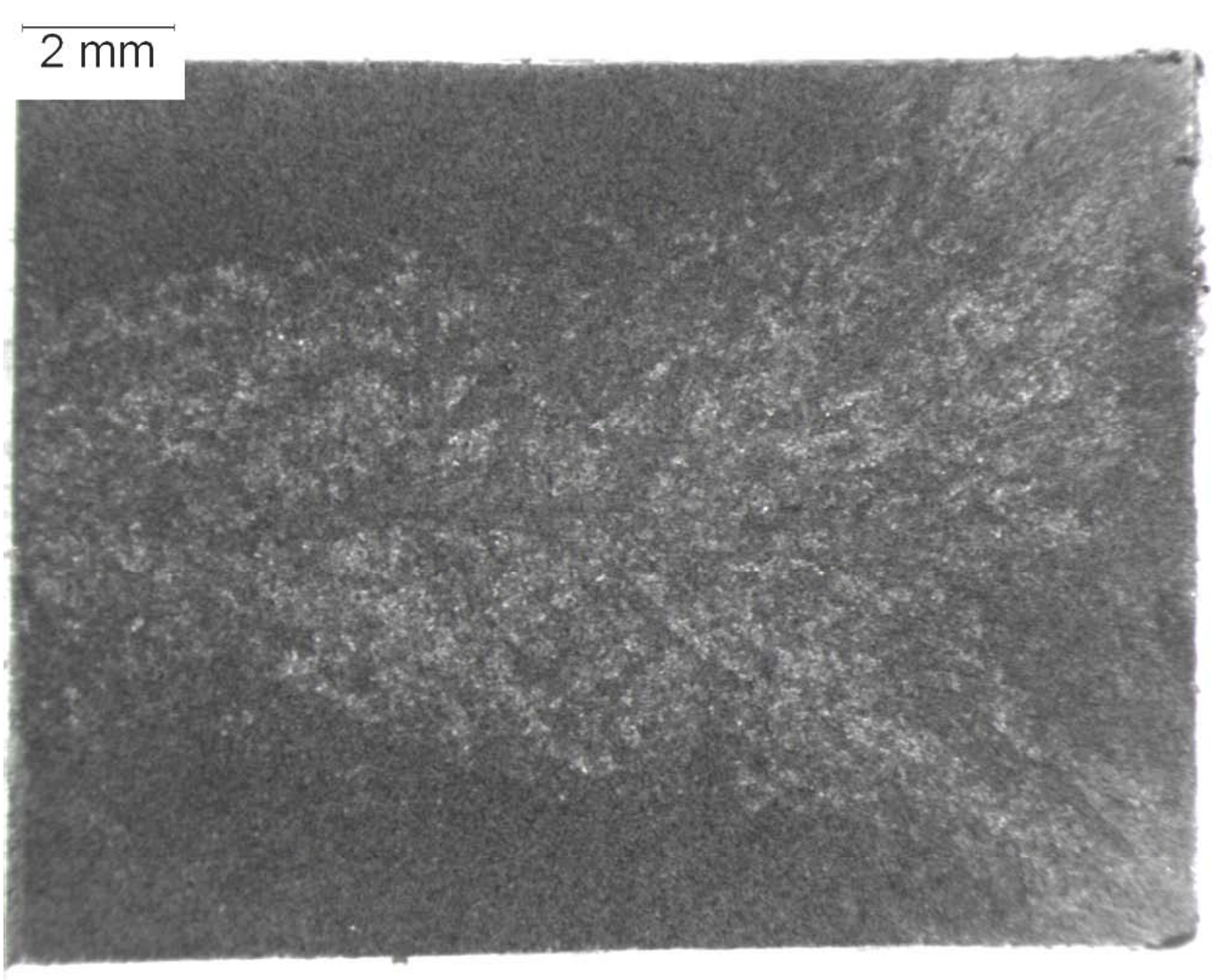
- Shape of Graphite
- Amount of Graphite (%TC - met. matrix C)
- Metallic Matrix (density)
  - % Pearlite
  - % Ferrite
  - % Martensite
- Carbides (reduces graphite volume)
- Porosity

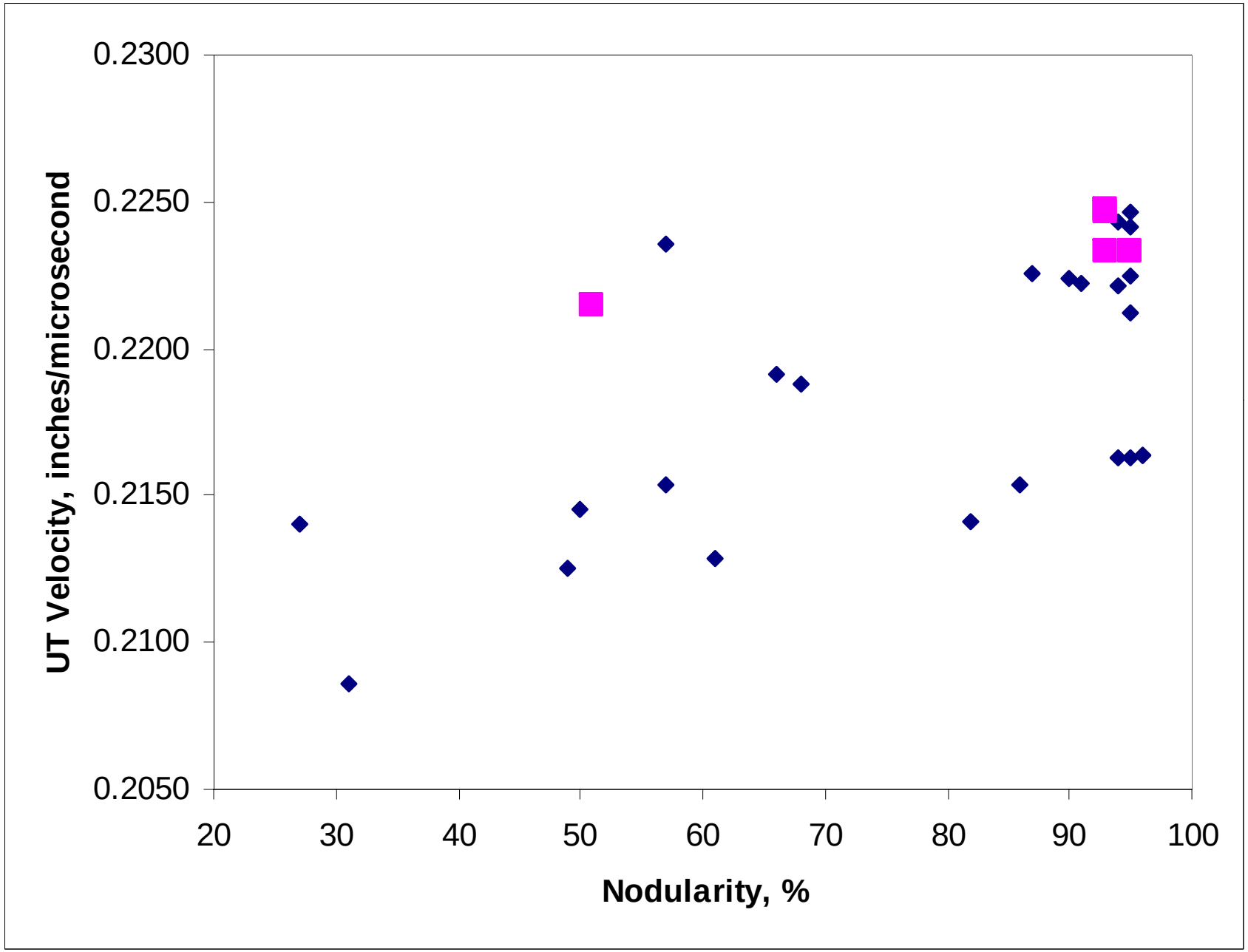
Carbides

- Fade will lead to carbides
- Carbides replace some of the graphite
- Causes the apparent UT velocity to rise
- Carbides can cause a false “high nodularity” reading



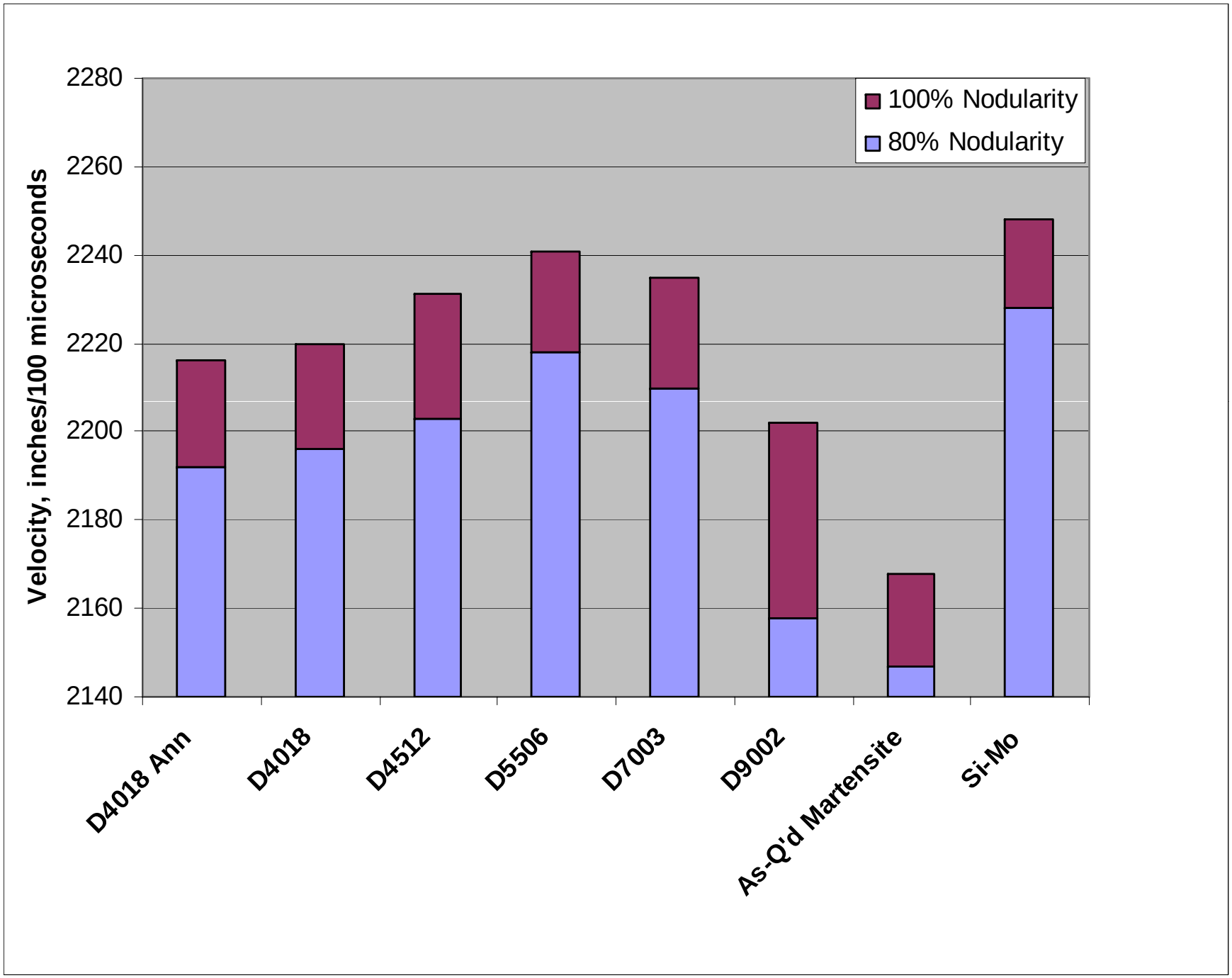

2 mm


2 mm


0.2300
0.2250
0.2200
0.2150
0.2100
0.2050
UT Velocity, inches/microsecond
20
30
40
50
60
70
80
90
100
Nodularity, %

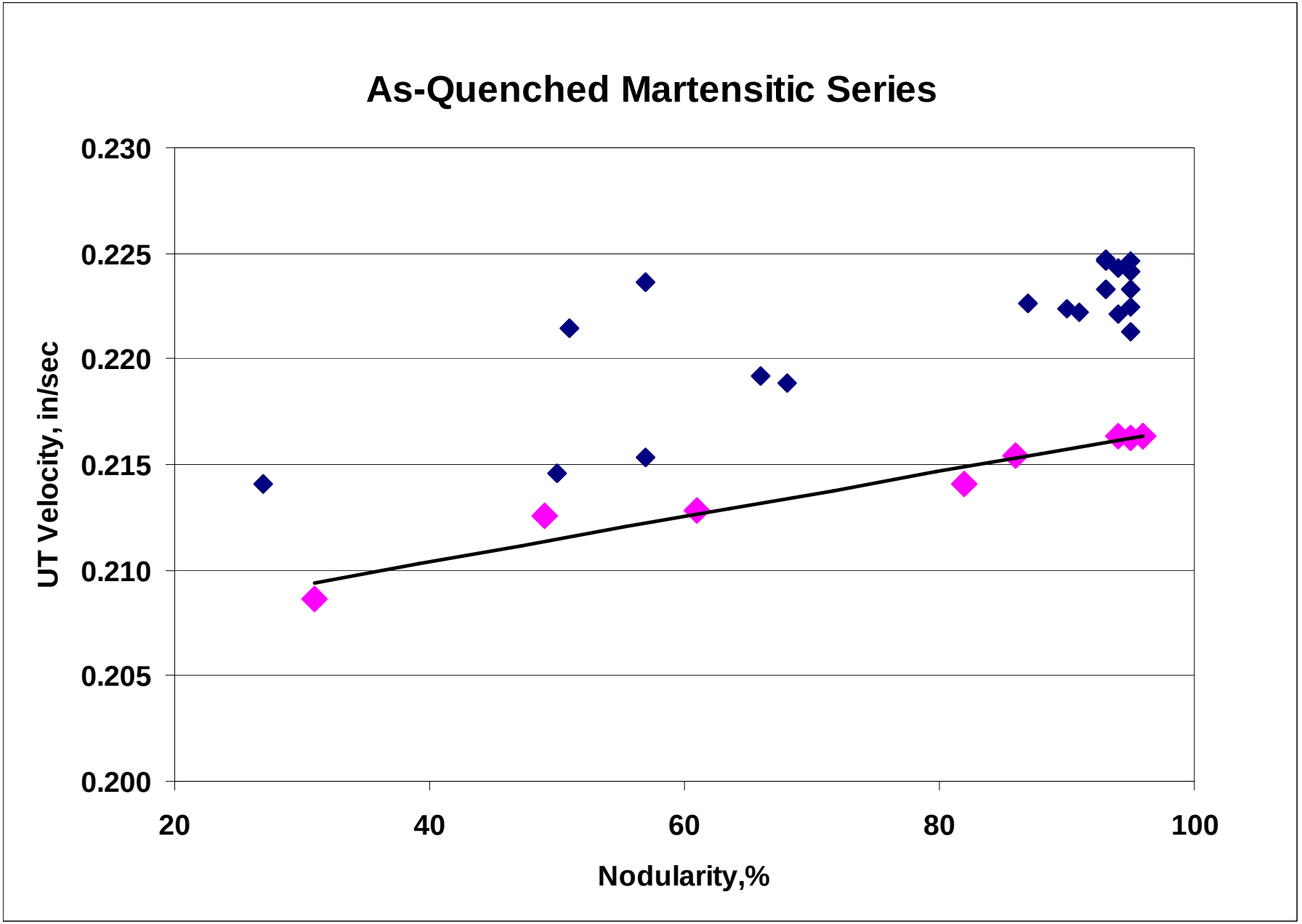
DENSITIES
of Microstructural Constituents

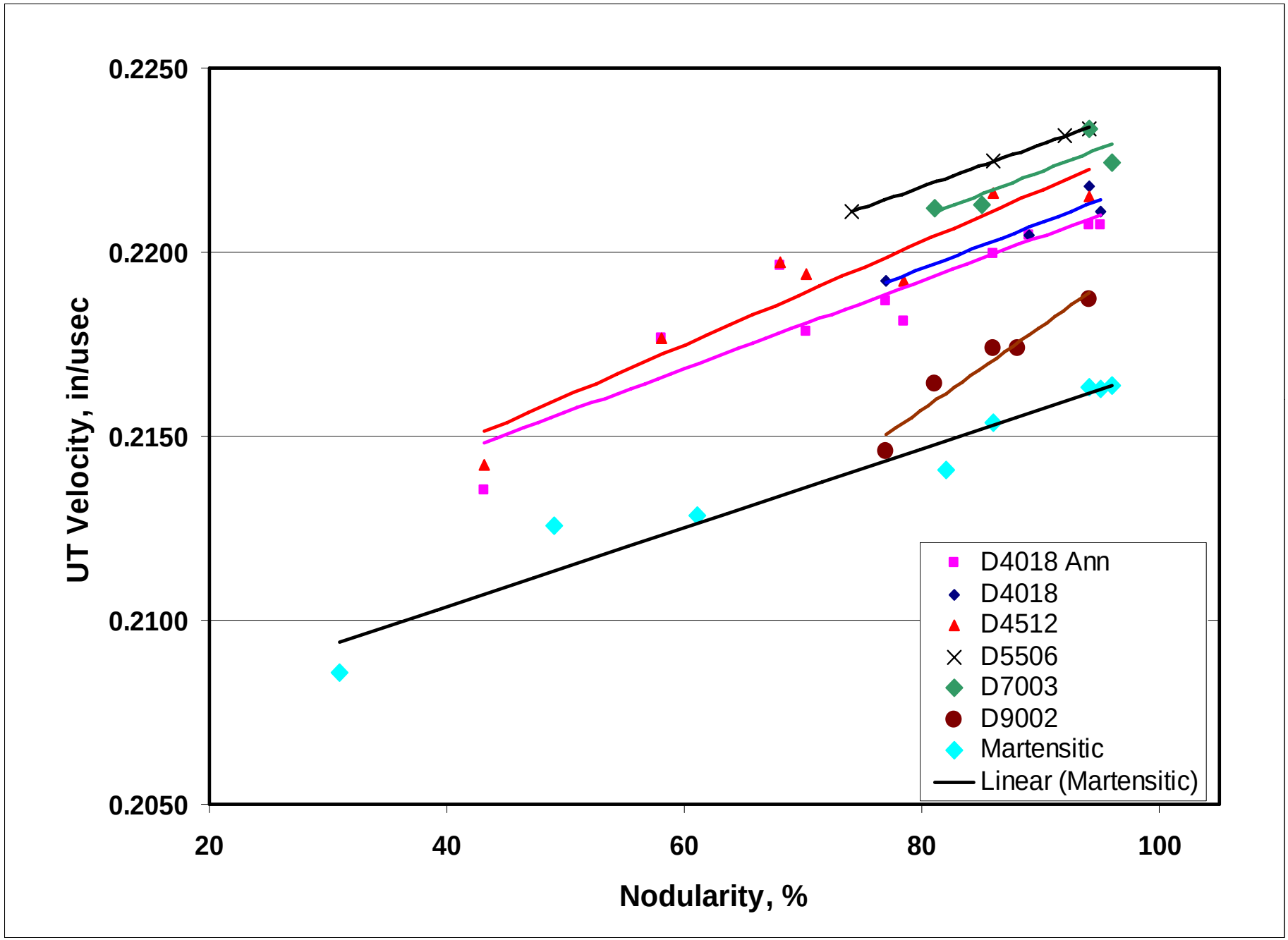
- Ferrite 7.86 g/cc
- Austenite 7.84 g/cc
- Pearlite 7.78 g/cc
- Cementite 7.66 g/cc
- Martensite 7.63 g/cc

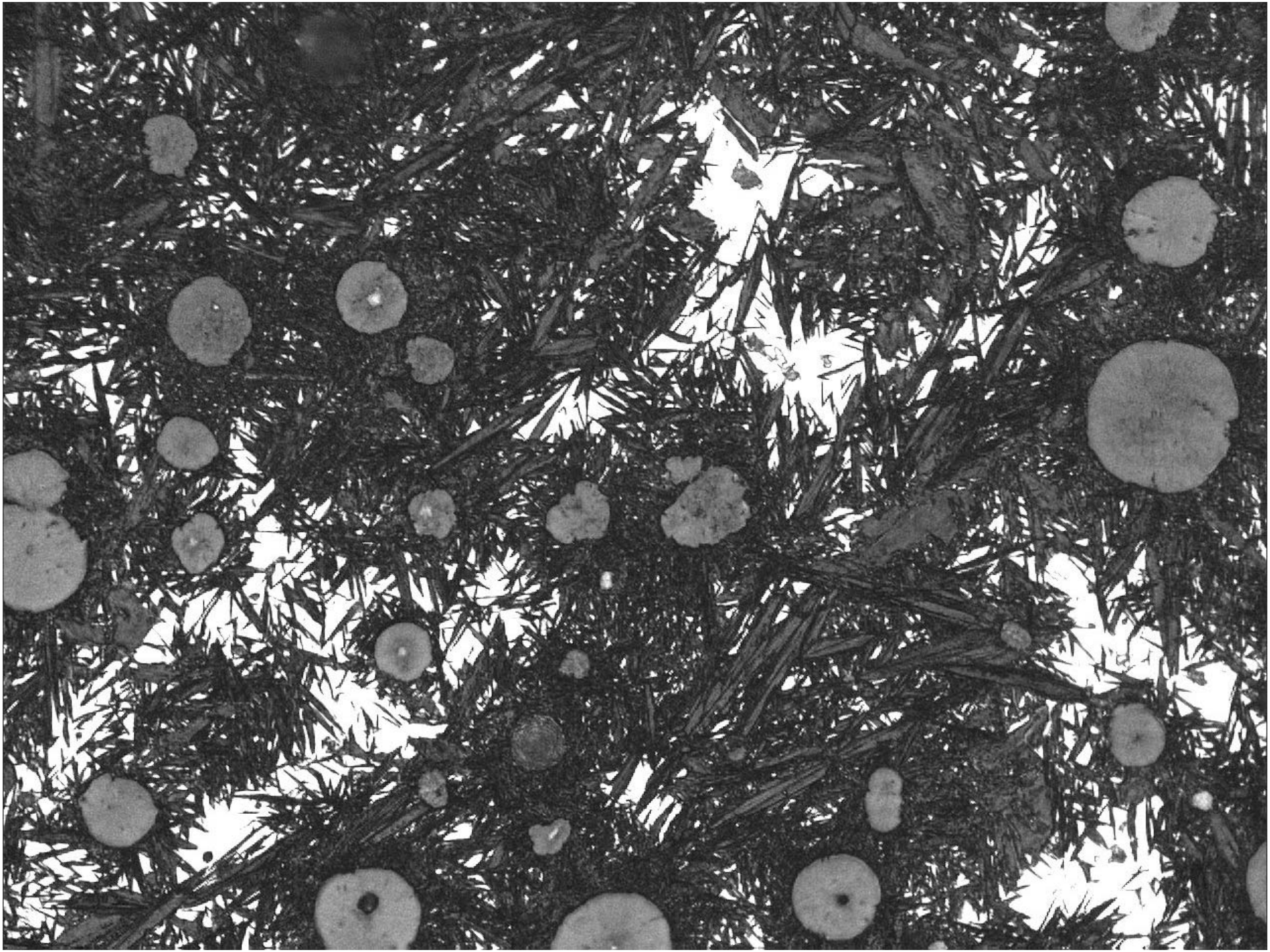

Velocity, inches/100 microseconds
2280
2260
2240
2220
2200
2180
2160
2140
100% Nodularity
80% Nodularity
D4018 Ann
D4018
D4512
D5506
D7003
D9002
As-Q'd Martensite
Si-Mo

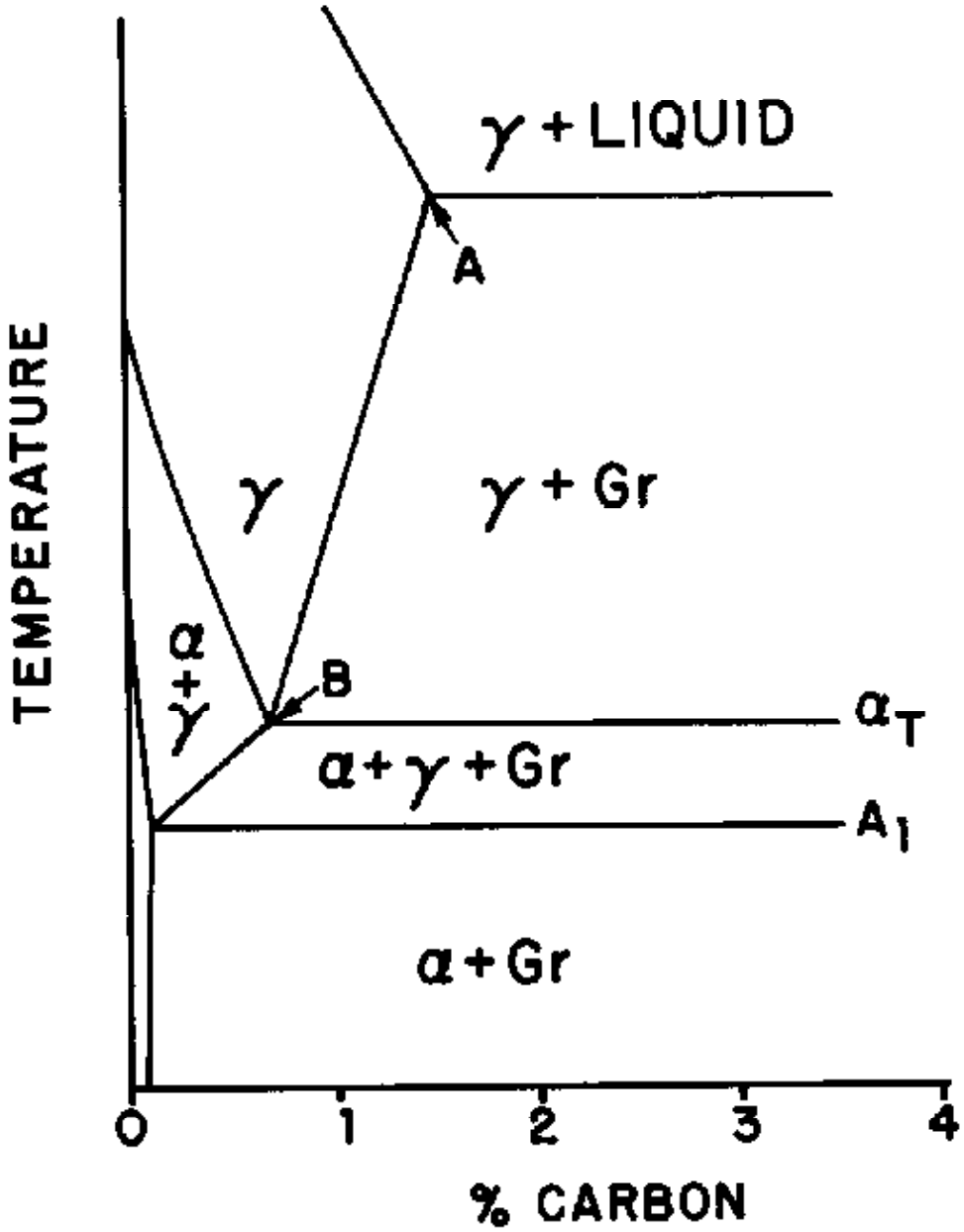
Fresh Martensite

- Fresh martensite has a very low density
- As-quenched samples contain retained austenite
- As-quenched samples contain varying amounts of dissolved carbon, depending on the temperature at which the sample was quenched.
- Consequently, the amount of free graphite and the amount of retained austenite (and the UT velocity) vary with the quenching temperature


As-Quenched Martensitic Series
0.230
0.225
0.220
0.215
0.210
0.205
0.200
UT Velocity, in/sec
20
40
60
80
100
Nodularity,%

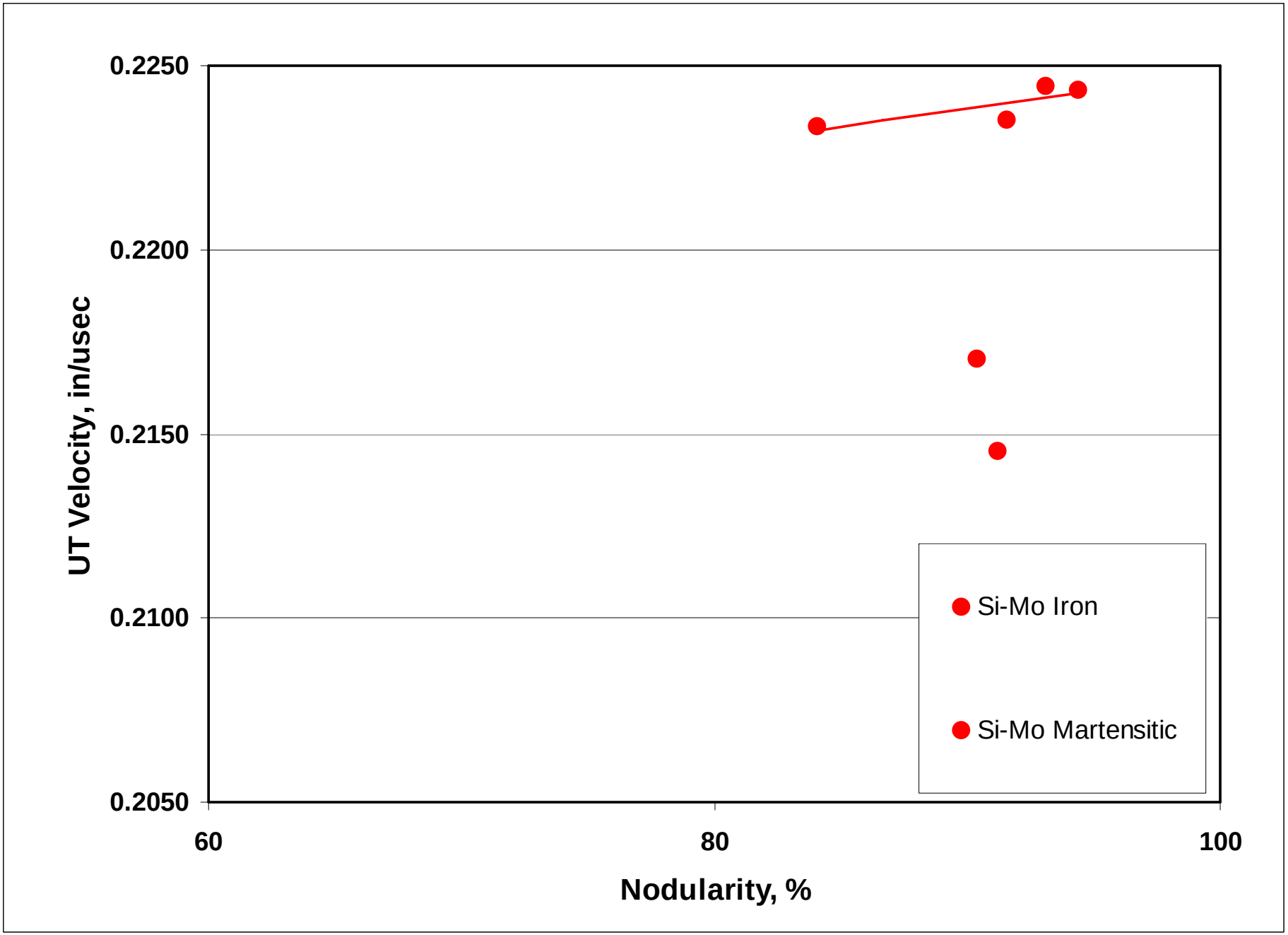

0.2250
0.2200
0.2150
0.2100
0.2050
UT Velocity, in/usec
20
40
60
80
100
Nodularity, %
D4018 Ann
D4018
D4512
D5506
D7003
D9002
Martensitic
Linear (Martensitic)

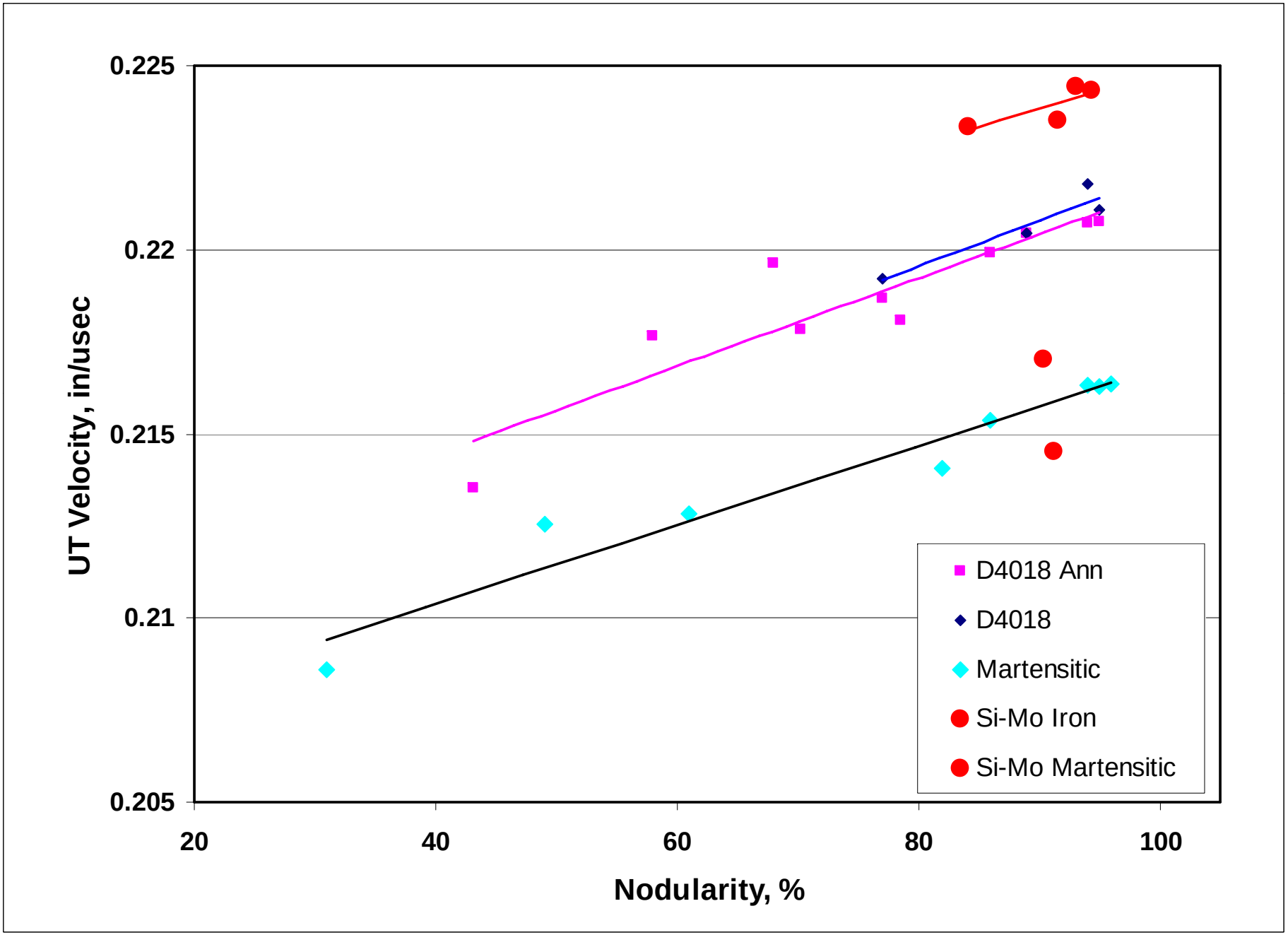


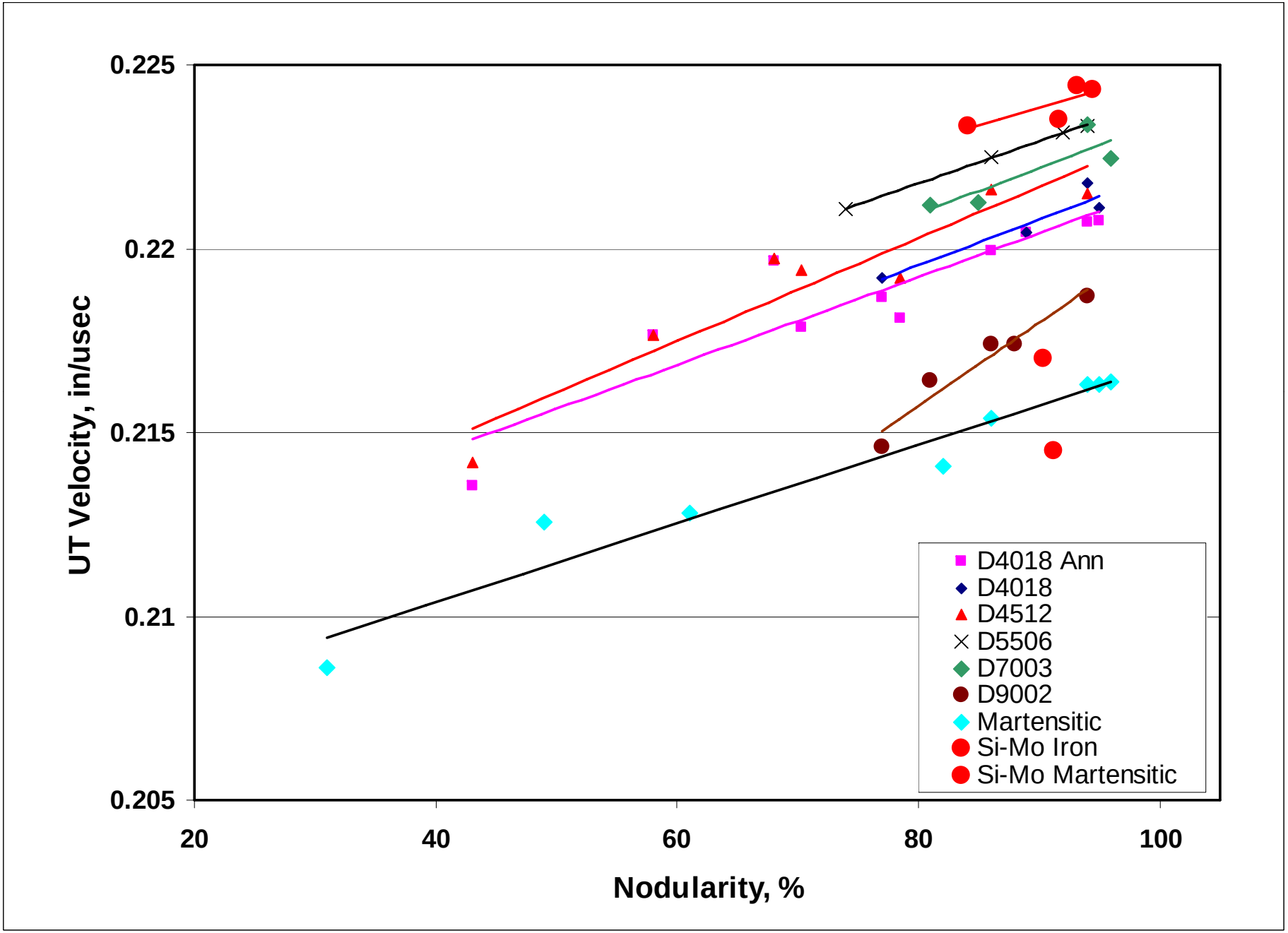

γ + LIQUID
A
γ
γ + Gr
γ+α
B
α_T
α+γ+Gr
A_1
α+Gr
TEMPERATURE
0
1
2
3
4
% CARBON

Si-Mo Ductile Iron

- Lower Carbon alloys with essentially fully ferritic structure and containing small amounts of carbides
- The total graphite volume less than conventional ferritic ductile iron
- Lower graphite volume expected to produce higher UT velocities


0.2250
0.2200
0.2150
0.2100
0.2050
UT Velocity, in/usec
60
80
100
Nodularity, %
Si-Mo Iron
Si-Mo Martensitic


0.225
0.22
0.215
0.21
0.205
UT Velocity, in/usec
20
40
60
80
100
Nodularity, %
D4018 Ann
D4018
Martensitic
Si-Mo Iron
Si-Mo Martensitic


0.225
0.22
0.215
0.21
0.205
UT Velocity, in/usec
20
40
60
80
100
Nodularity, %
D4018 Ann
D4018
D4512
D5506
D7003
D9002
Martensitic
Si-Mo Iron
Si-Mo Martensitic

CONCLUSIONS

- UT velocity influenced primarily by graphite shape
- UT velocity influenced by graphite volume
- UT velocity increases with chill carbides
- UT velocity varies with matrix microstructure and grade
- Martensitic matrix appears to produce a consistent curve for all grades

RECOMMENDATIONS

Since an as-quenched martensitic matrix appears to produce a consistent curve for all grades

- Investigate the influence of retained austenite in as-quenched martensitic samples
- Investigate the influence of quenching temperature on retained austenite and UT velocity
- Investigate the influence of quenching time on UT velocity