

Interlamellar Spacing and Pearlite Hardness: A Literature Review

Gene Muratore

Rio Tinto Iron and Titanium

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Outline

- Credits
- Commodity Pricing
- Formation of Pearlite
- Chemistry/Cooling Rate Effects
- Hardening Pearlite
- Conclusions

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

CoAuthors

- **Chantal Labrecque-Research Engineer, RTIT Technology**
- **Felipe Oruna-Intern, RTIT Technology**

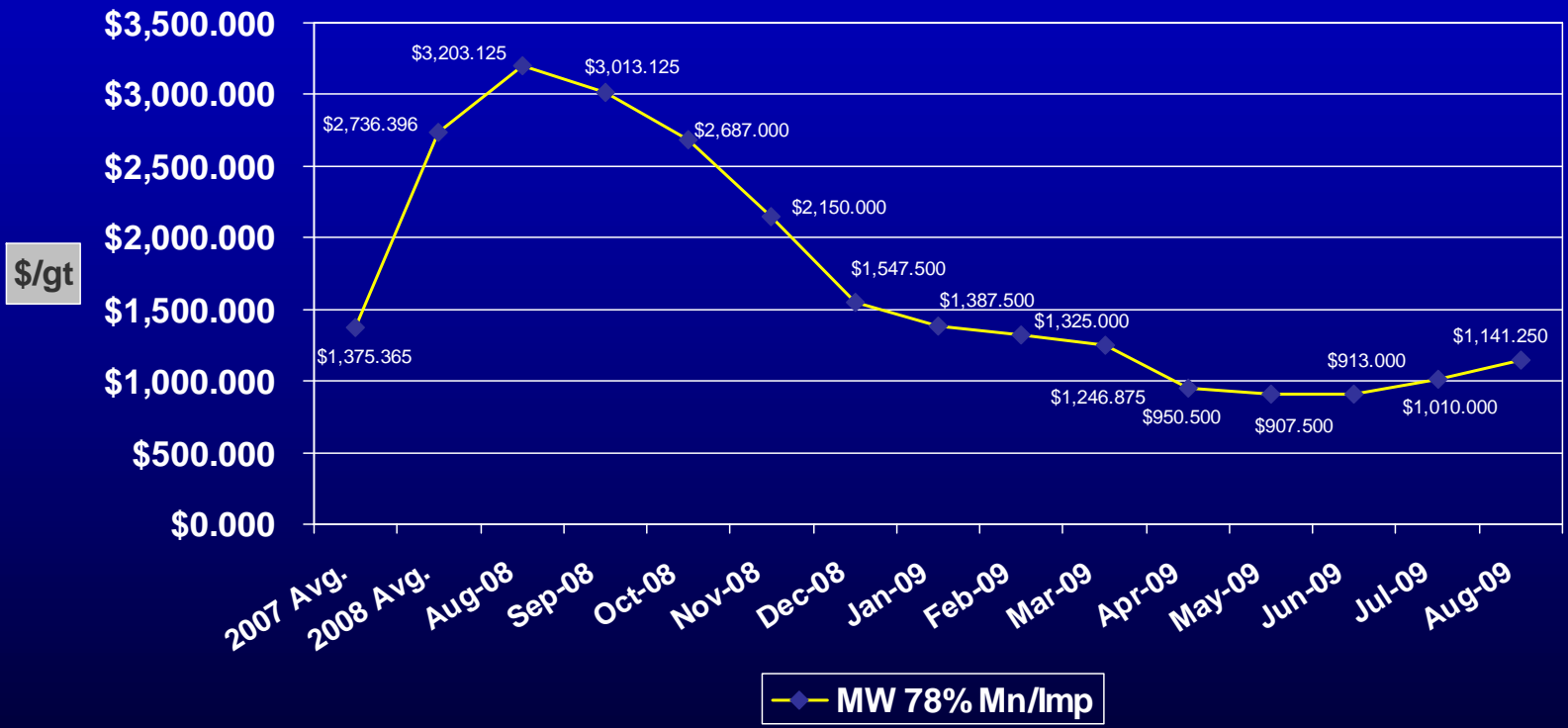
*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Driving Forces

- **Commodity Pricing**
- **Commodity Availability**
- **Changing Chemistry of the Scrap Steel Stream**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

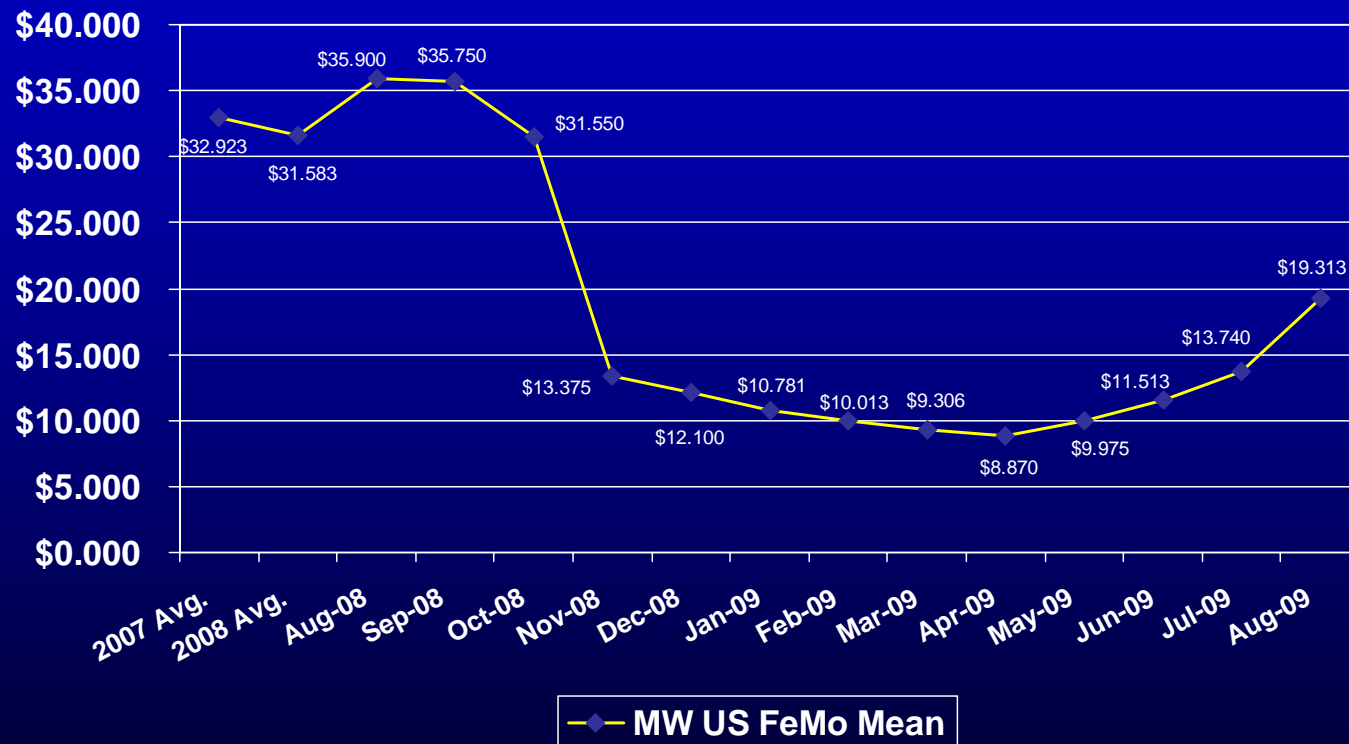
FerroManganese



*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

FerroMolybdenum

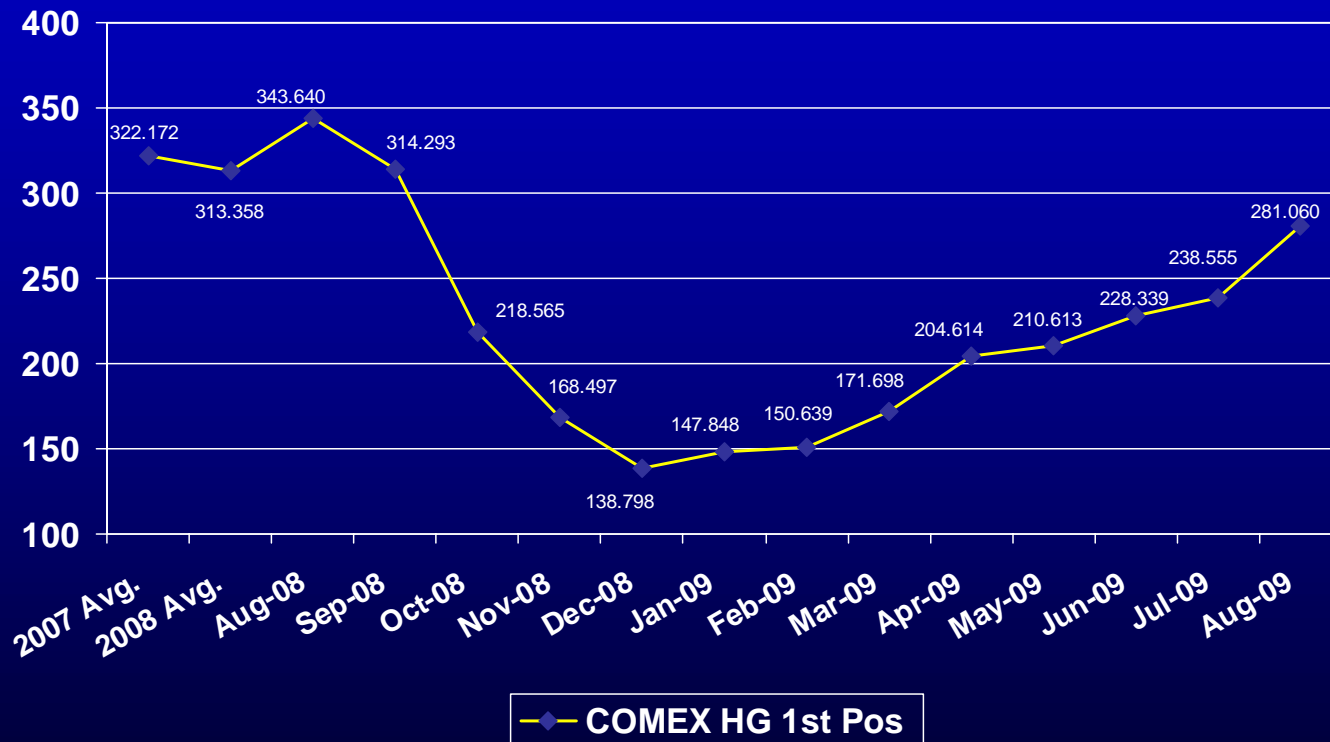
\$/LB Ctd



DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009

Copper

CTS/LB



*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Additional Driving Force

- **Special Iron Producers (SiMo) also looked at options.**
- **Patents?**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

More Driving Forces

- **Higher Strength to Weight Ratios in Iron and Steel.**
- **Both materials compete in the design arena.**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Pearlite vs Strength

- **Increased pearlite => Higher strength**
- **Decreased interlamellar spacing => Higher strength due to finer pearlite**

Formation of Pearlite

- **Solid State Transformation of Austenite to ferrite + cementite below the eutectoid temperature.**
- **Aided by any method that inhibits carbon diffusion.**
- **Diffusion affected by:**
 - **Chemical Composition**
 - **Cooling Rate**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Chemistry Effects

- **Sn, Sb, As, Cu - act as diffusion barriers**
- **Mn & Cr – Hold carbon in solution**
- **Net Effect: Both increase carbon in cooling austenite => more pearlite**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Cooling Rate Effect

- Reduces the time for carbon diffusion
- Increases carbon content in austenite at lower transformation temperatures.

Cooling Rate Effect

- **Net Effect: Higher carbon content austenite @ lower transformation temperature => smaller interlamellar spacing = finer pearlite.**

Limitations

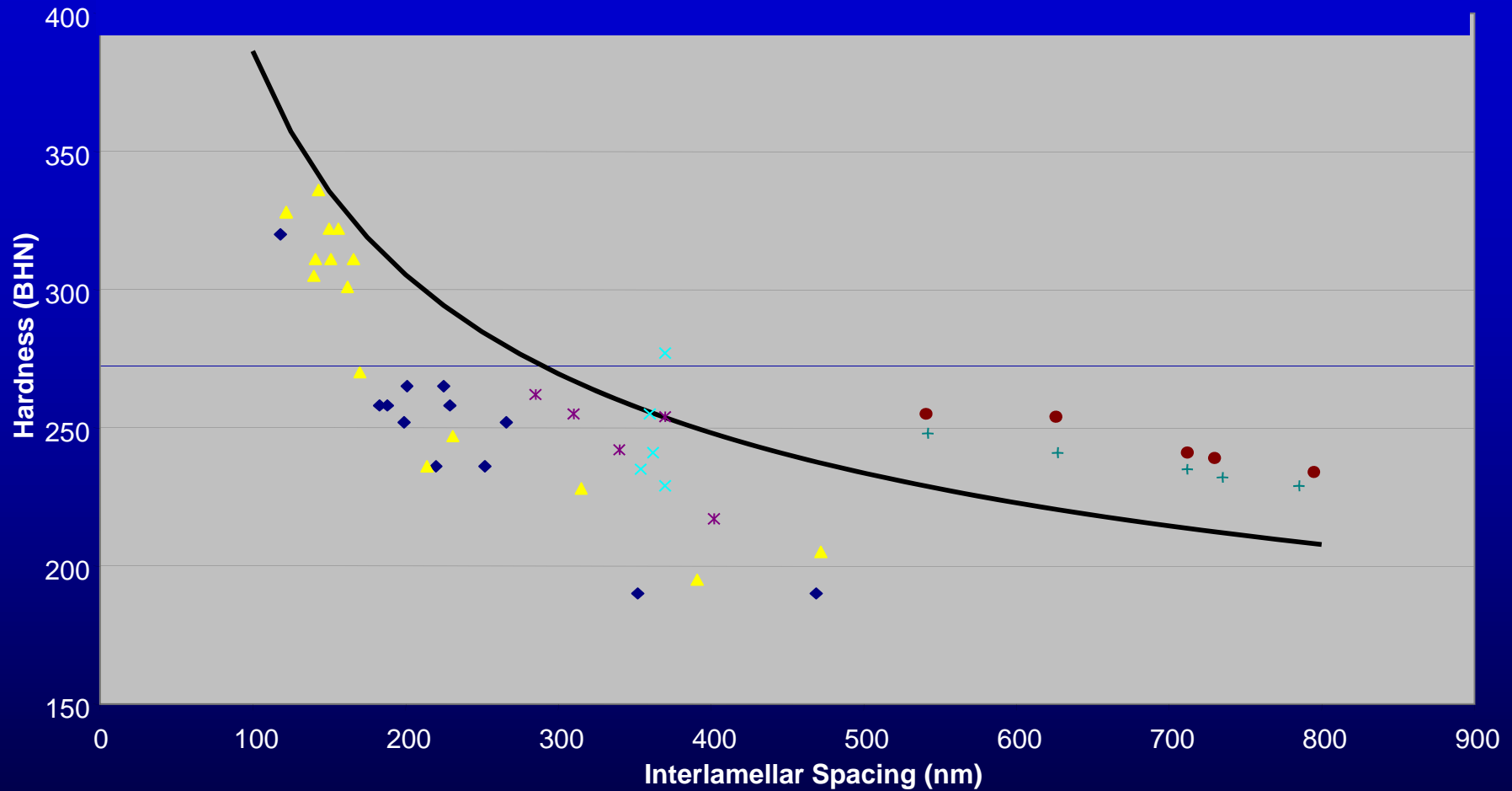
- **Change Modulus? Design considerations**
- **Use Chills or higher conductivity molding medium? Cost.**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Measuring Interlamellar Spacing

- Several methods described in the literature
- Caution when comparing work from varying sources.

Interlamellar Spacing vs Hardness



— Modeled (Hall-Petch) ◆ Carbon steel ▲ Chromium steel × Hypoeutectoid steel
* Eutectoid steel (A) ● Hypereutectoid steel + Eutectoid Steel (B)

DIS T&O Meeting, West Middlesex, PA

September 30, October 1, 2009

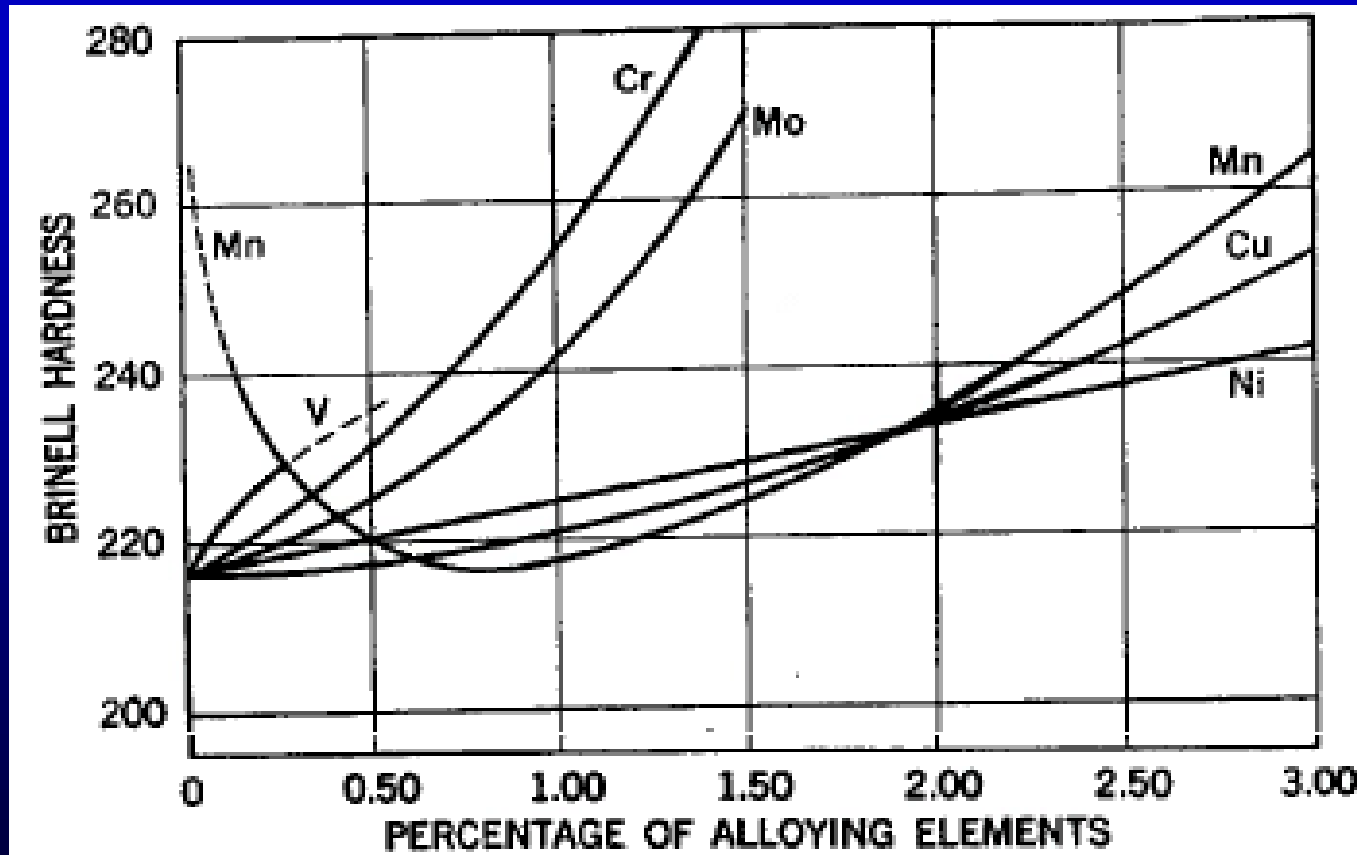
Hardness Prediction Equation (After Catalina)

$$\textit{Hardness (BHN)} = 110 + \frac{87,4}{\sqrt{\lambda}}$$

λ is the mean apparent spacing in μm .

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Effect of Alloying on Brinell Hardness



*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Hardness Increases

- **Bulk Hardness can be increased by additions of single alloys.**
- **Combinations of alloys are often synergistic and more effective.**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Alloy Combinations

- **Mo + Ni**
- **Cu + Sn + Mo**
- **Mo + Cu**
- **Mo + Cr**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Softening Alloys

- **Silicon**
- **Cobalt**

- **Should be minimized**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Cautions

- Pearlite refining elements that are effective in steels will not necessarily be effective in cast irons.
- Examples: Mn & Cr

Segregation Factors

- Mo 25.3
- Ti 25.0
- V 13.2
- Cr 11.6
- Mn 1.7-3.5
- P 2.0

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Summary

| Element | Material | Effect on Spacing | Reference |
|---------|-----------|-------------------|-----------|
| Sn | GI | None | 3 |
| As | GI | None | 3 |
| Sb | GI | None | 3 |
| Cr | GI | Sm Reduction | 3 |
| Cr | Eut Steel | Increase | 9 |
| Cr | Steel | Med Reduction | 10 |
| Cu | GI | Sm Reduciton | 3 |
| Cu | DI | Med Reduction | 12 |
| Mn | GI | Med Reduction | 3 |
| Mn | Steel | Increase | 10 |
| Mn | DI | Med Reduction | 12 |
| Mo | GI | Str Reduction | 3 |
| Mo | Eut Steel | Increase | 9 |
| Mo | Steel | Str Reduction | 10 |

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Further Pearlite Hardening

- Only the ferrite portion of the pearlite can be hardened.
- Only selected elements will harden ferrite, as others will concentrate in the cementite region.

Possible Pearlite Hardeners

- V
- Cr
- Mo

- C
- N
- Si
- Cu
- Mn

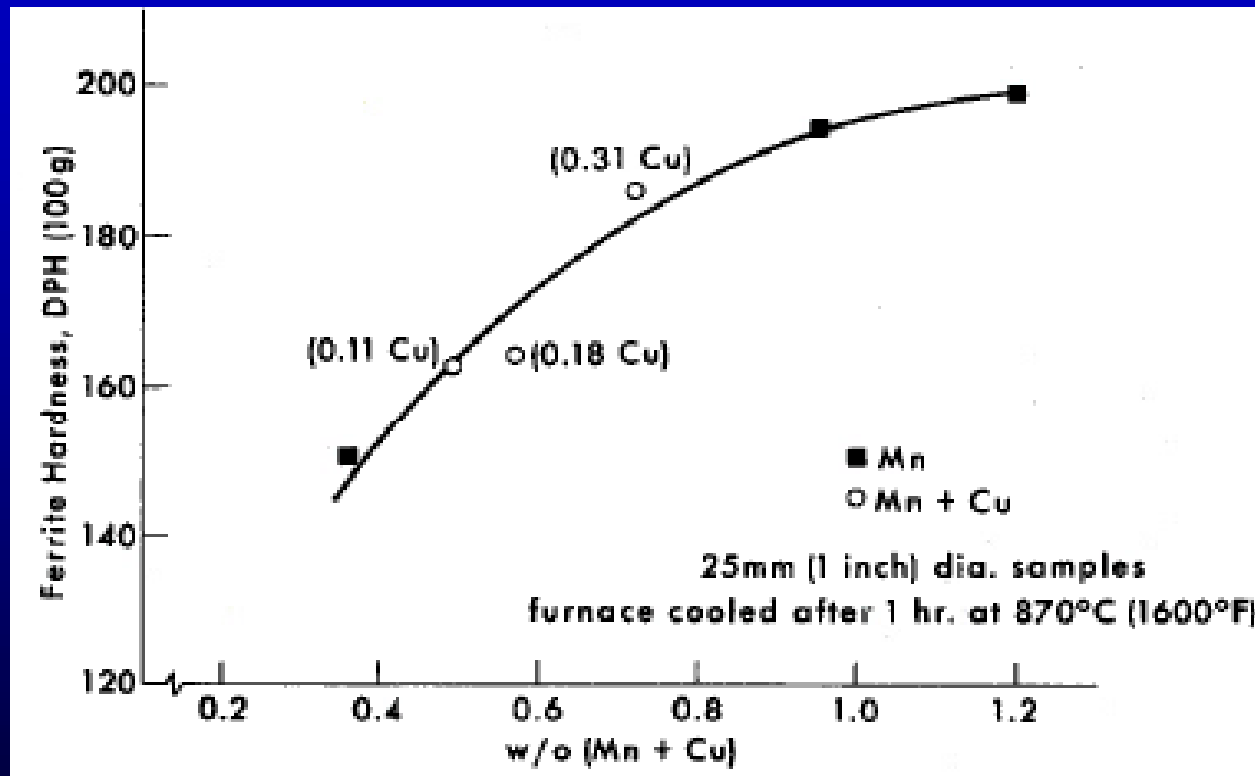
*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Effective Pearlite Hardeners

- **C** **Low solubility in ferrite**
- **N** **Low solubility in ferrite**
- **Si**
- **Cu**
- **Mn**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Synergistic Effect of Cu + Mn on Ferrite Hardness



*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Conclusions

- Alloy prices are volatile
- Increases in pearlite percentage lead to increased strength and hardness
- Chemistry and cooling rate determine pearlite content and spacing.
- Measurement of pearlite spacing is not unified

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Conclusions Cont'd

- **Finer Spacing (shorter interlamellar spacing) yields higher hardness**
- **Steels and Cast Irons vary in their response to alloy additions**
- **Alloy additions can be synergistic**
- **The ferrite portion of pearlite can be hardened.**

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*

Thank You

Questions?

*DIS T&O Meeting, West Middlesex, PA
September 30, October 1, 2009*
