Flash Microstructure

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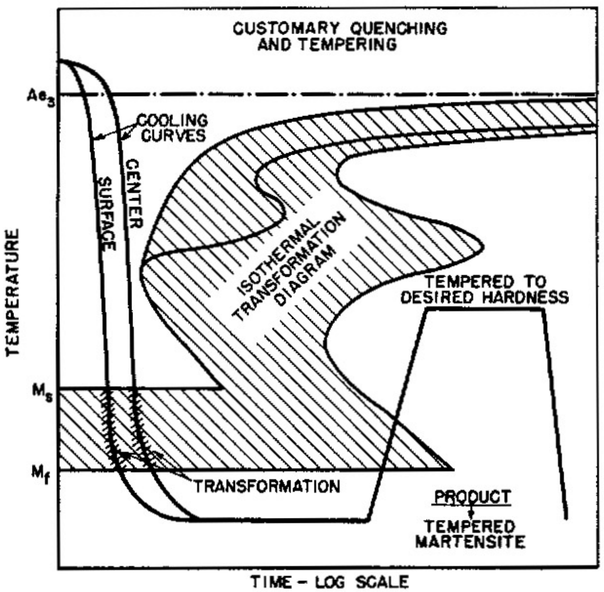
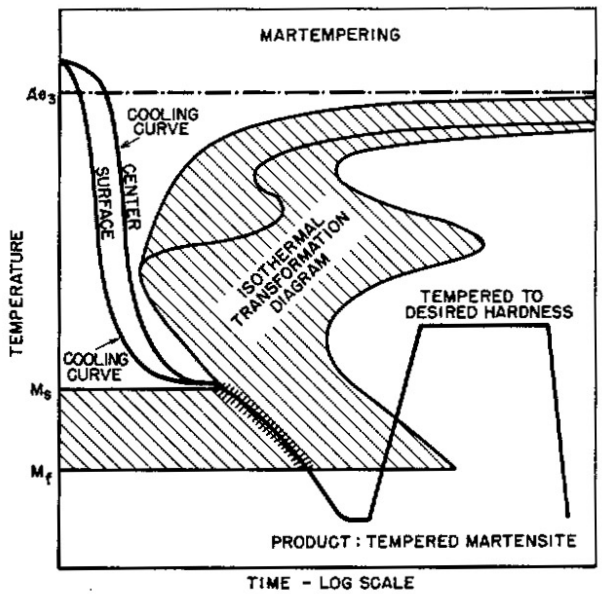
CIMJSEA

Traditional processes to achieve good combination of strength and toughness

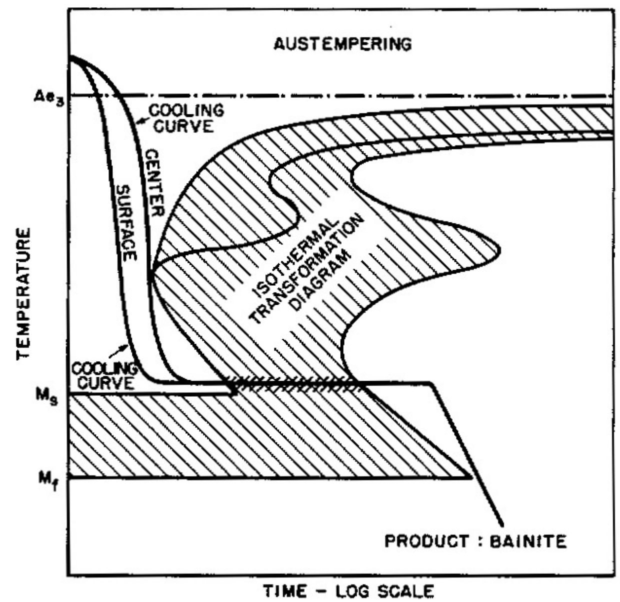
Q&T



Mar-Tempering



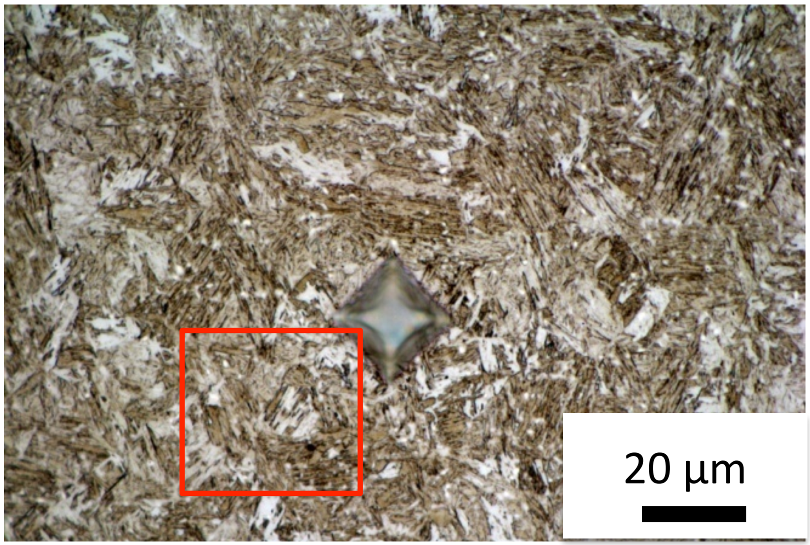
Aus-Tempering

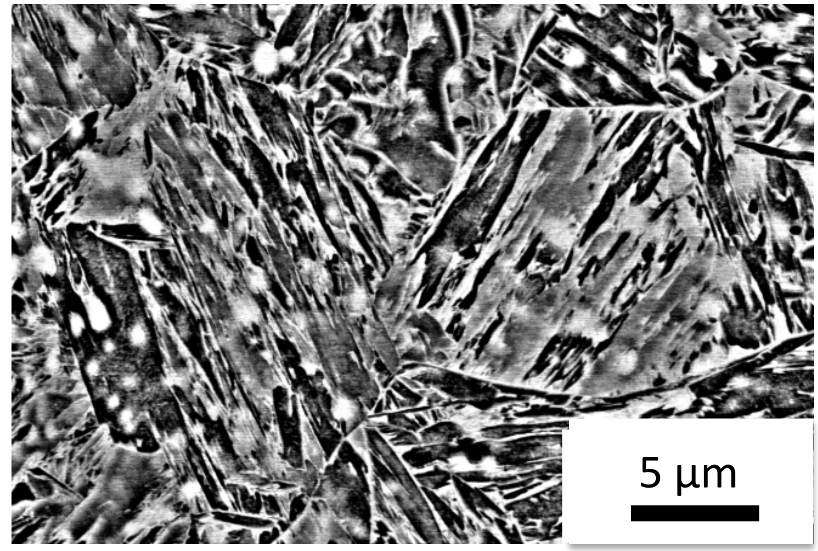


Ref: ASM Handbook

- New Strategy: Flash processing

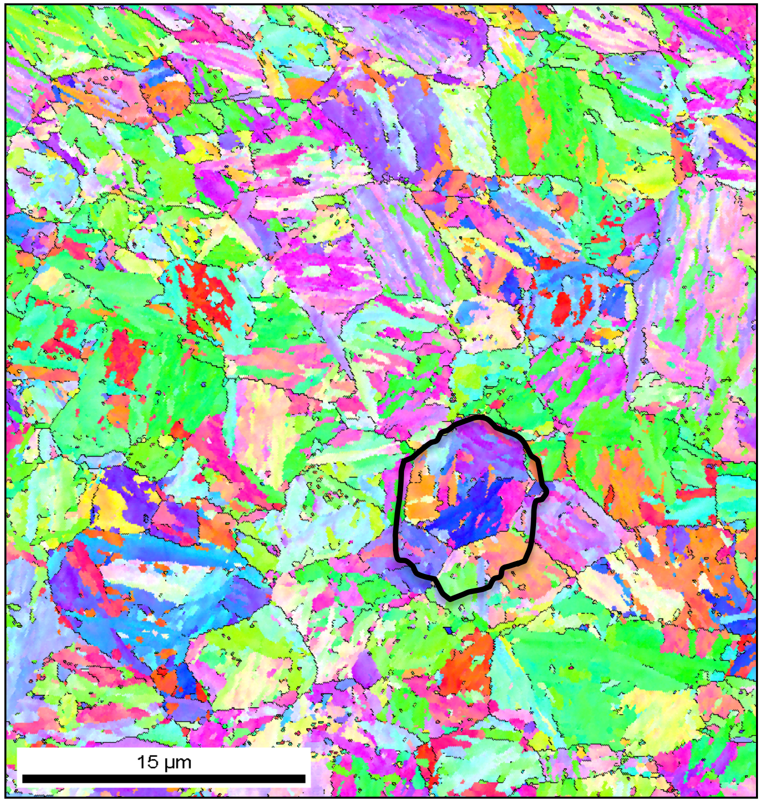
What is flash microstructure?

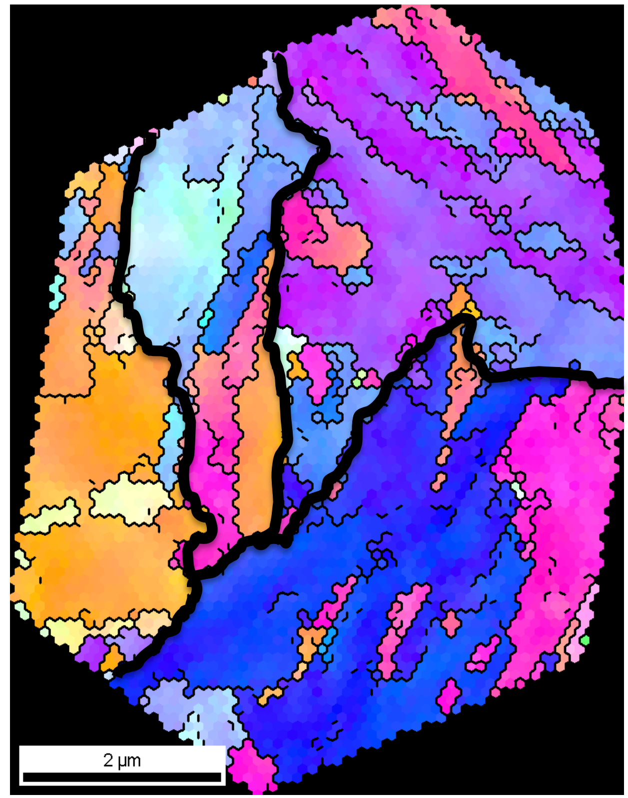


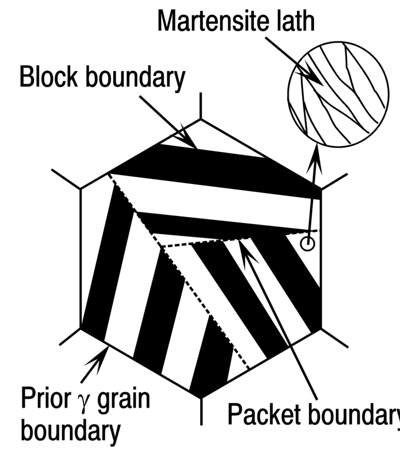


- Small Prior Austenite Grain Size (<20 µm)
- Mixed Bainitic/Martensitic Microstructure
- Uniform Distribution of Carbides

Flash Microstructure Contains Fine Bainitic/Martensitic Packets



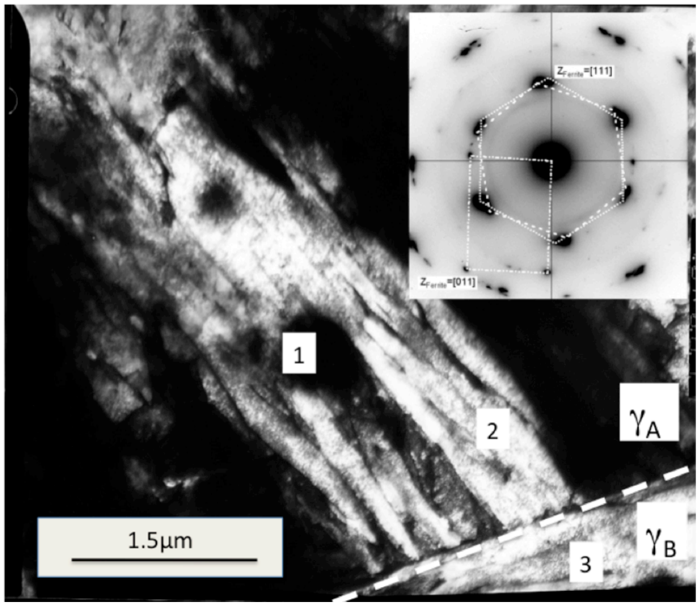


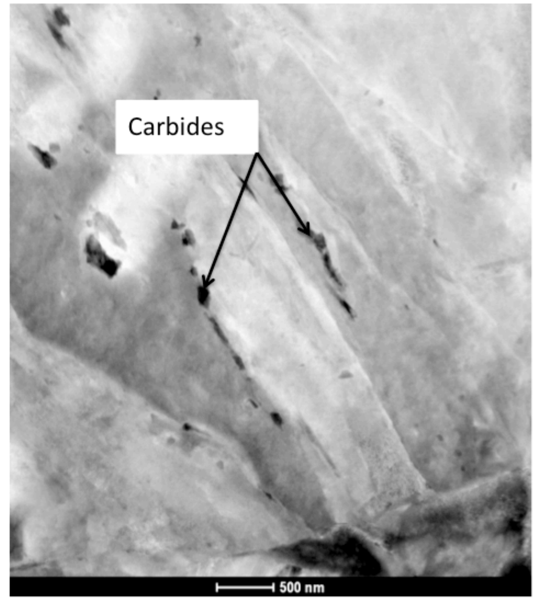


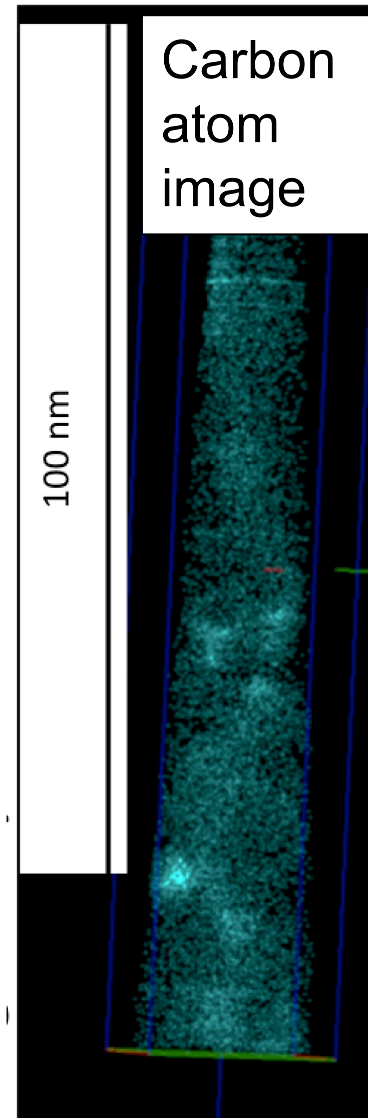
(T. Maki, K. Tsuzaki, I. Tamura: Trans. ISIJ, 20 (1980), 207-214)

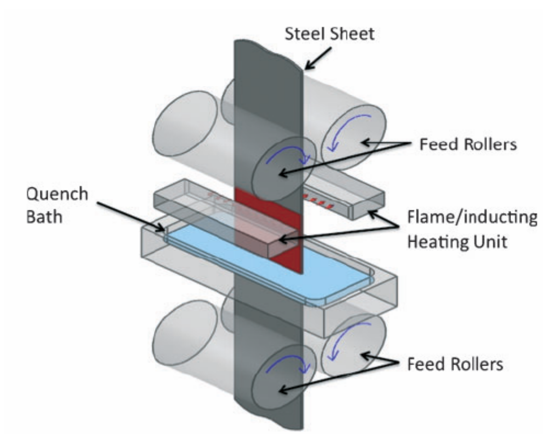
- Is it bainite or martensite? What are these carbides?

Mixed Microstructure [Bainitic/Martensitic Laths with Alloy Cementite] is confirmed



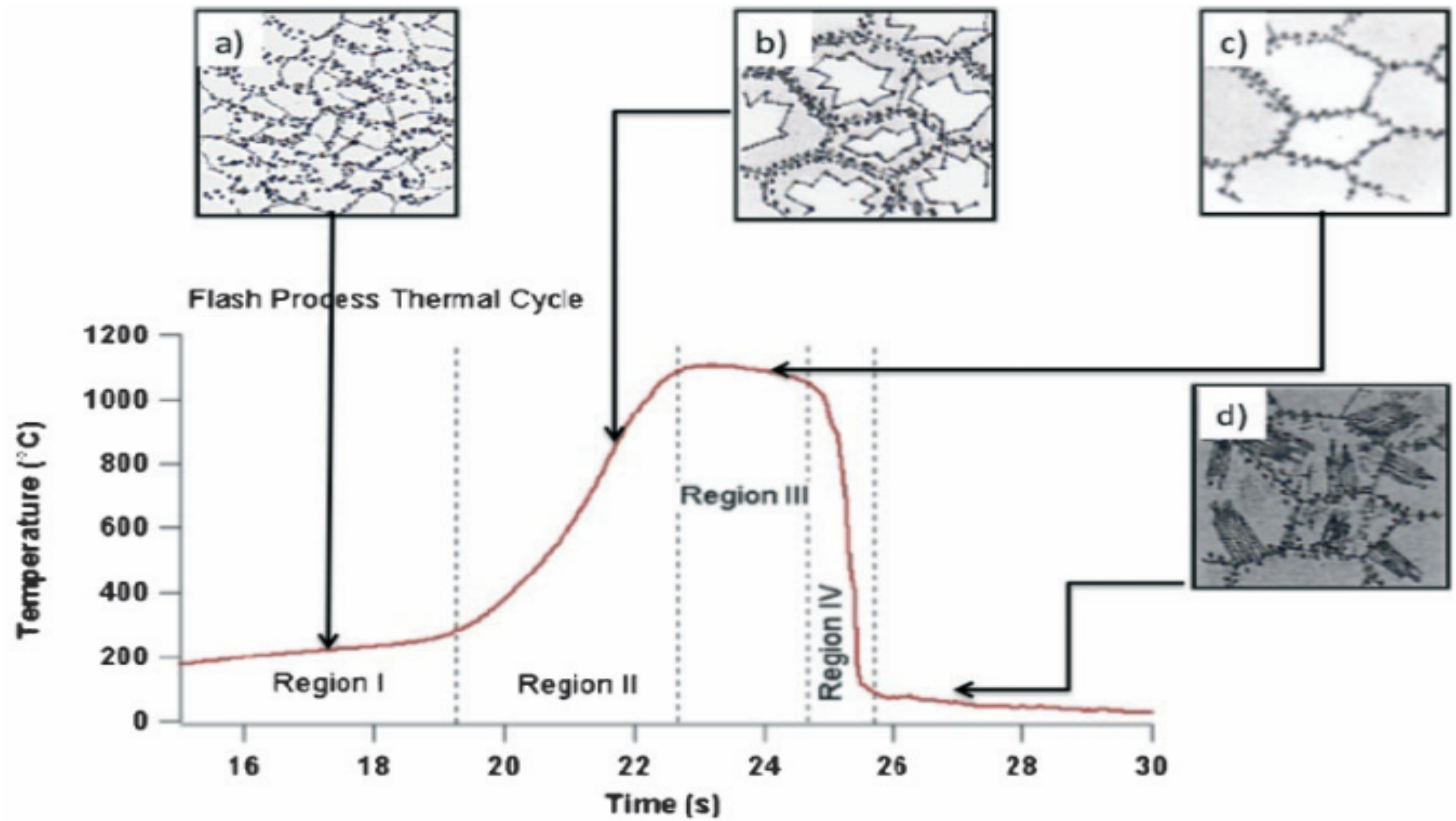






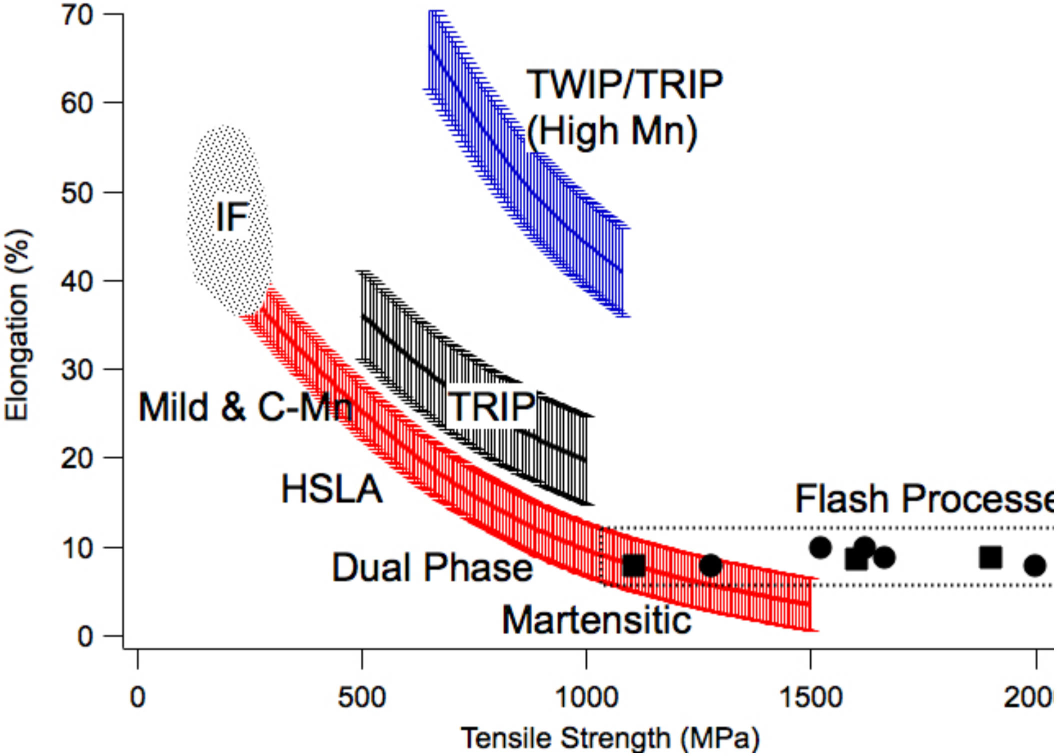
- What is so unique about the flash processing that leads to such a microstructure?

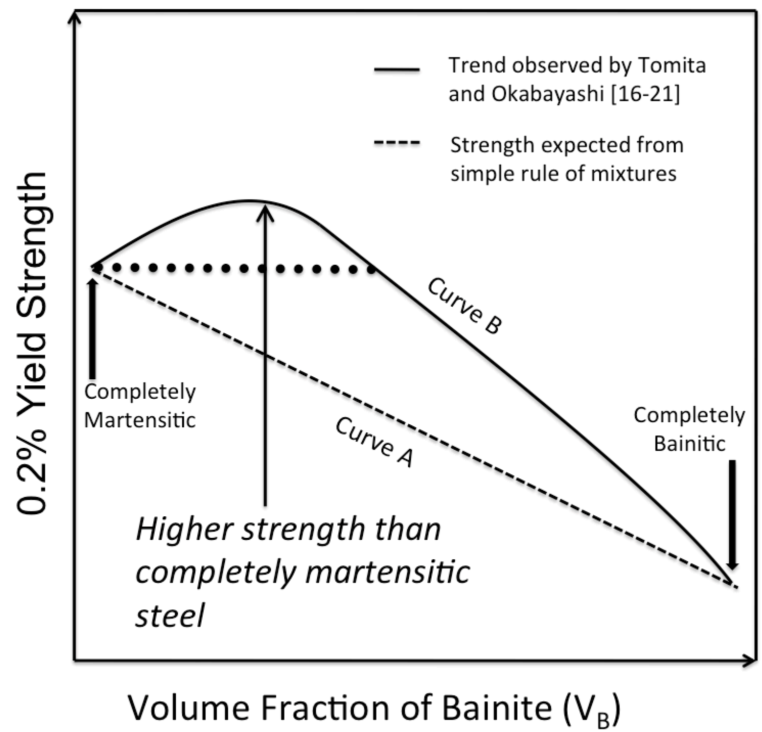
<u>Mechanism</u>: Rapid heating, short hold-time, un-dissolved carbides, carbon inhomogeneity in austenite & rapid cooling cooling ➔ mixed microstructure



- How does flash microstructure affect properties?

Tensile Properties of Flash Microstructure



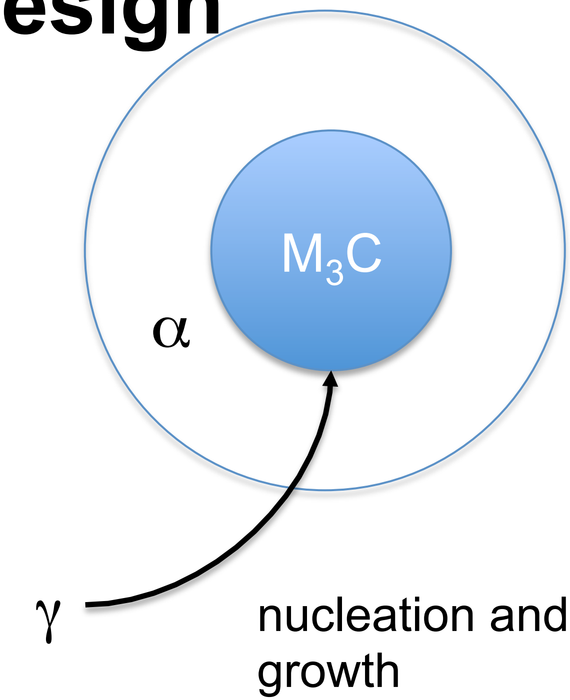


- Hypothesis: Mixed Bainitic and Martensitic lead to unique properties

How can we design flash processing?

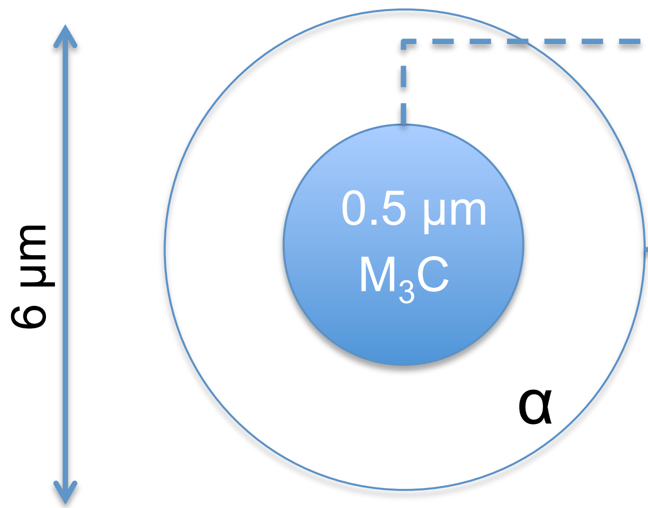
Previous research on re-austenitization kinetics ➔ base line for design

- Initial Microstructure Effects (Ling, Reed and Owen, 1985)
- Isothermal Dissolution of cementite (Liu, 1991)
- Akbay, Reed and Atkinson (1995)
- K. D. Clarke et al (2010) during induction heating (300°C/s)
  - Austenitization in ferrite + pearlite & tempered martensite microstructures
- Miyamoto et al (2010) on isothermal dissolution of spherodized cementite



- Current Research: Calculation of M_3C Dissolution during continuous heating with and without Cr

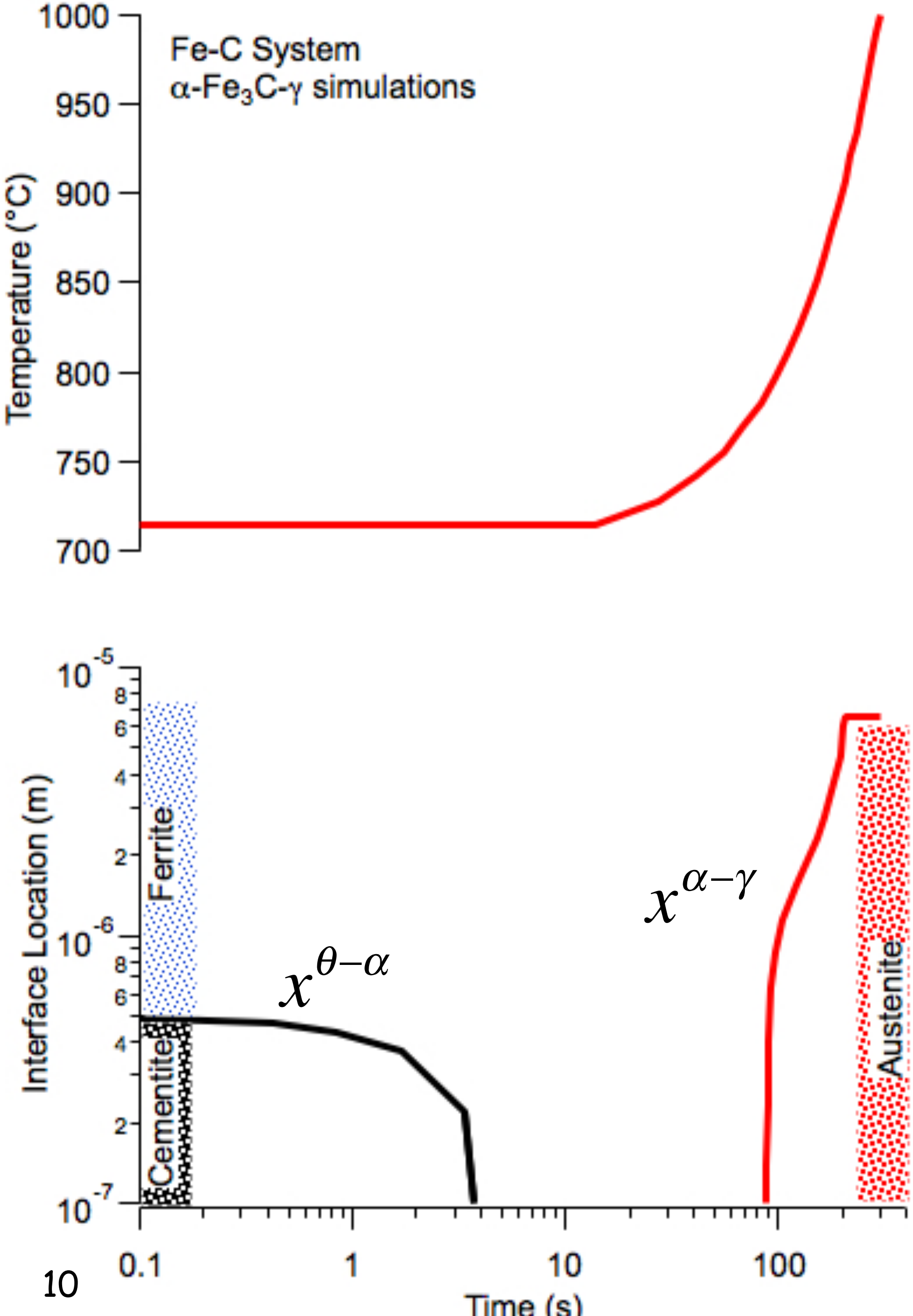
DicTra® Simulation: Fe-C & Fe-Cr-C system



Cementite (M_3C)
Fe-C System:
Fe – 25 at. % C
Fe-Cr-C System:
Fe – 25 at. %C-13.3 wt.% Cr

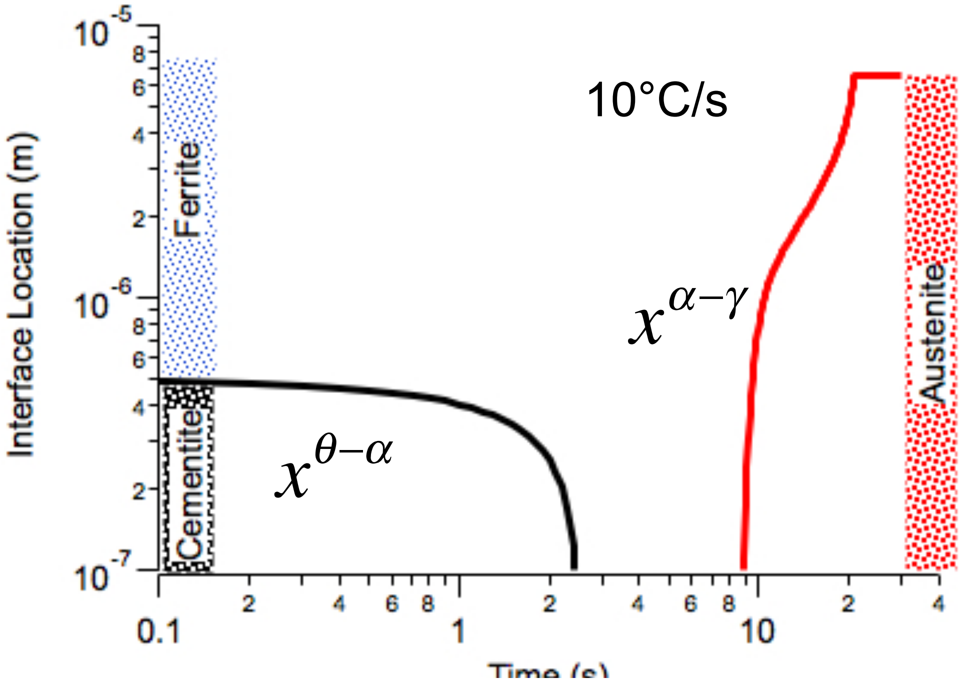
Ferrite
Fe-C System:
Fe -0.01 wt. % C
Fe-Cr-C System:
Fe-0.01wt. %C-0.33 wt.%Cr-

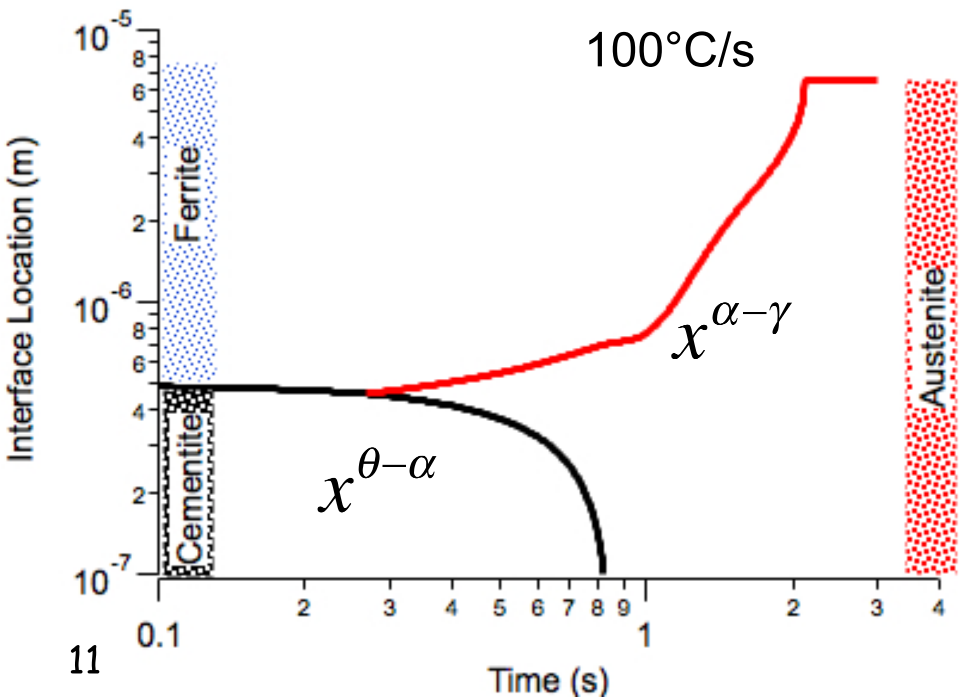
- Austenite was allowed to form at α/M_3C interfaces
- Grows into both cementite and ferrite
- Heating rate 1, 10 & 100°C/s



Simulations for α-γ-Fe_3C Heating Rate: 1°C/s

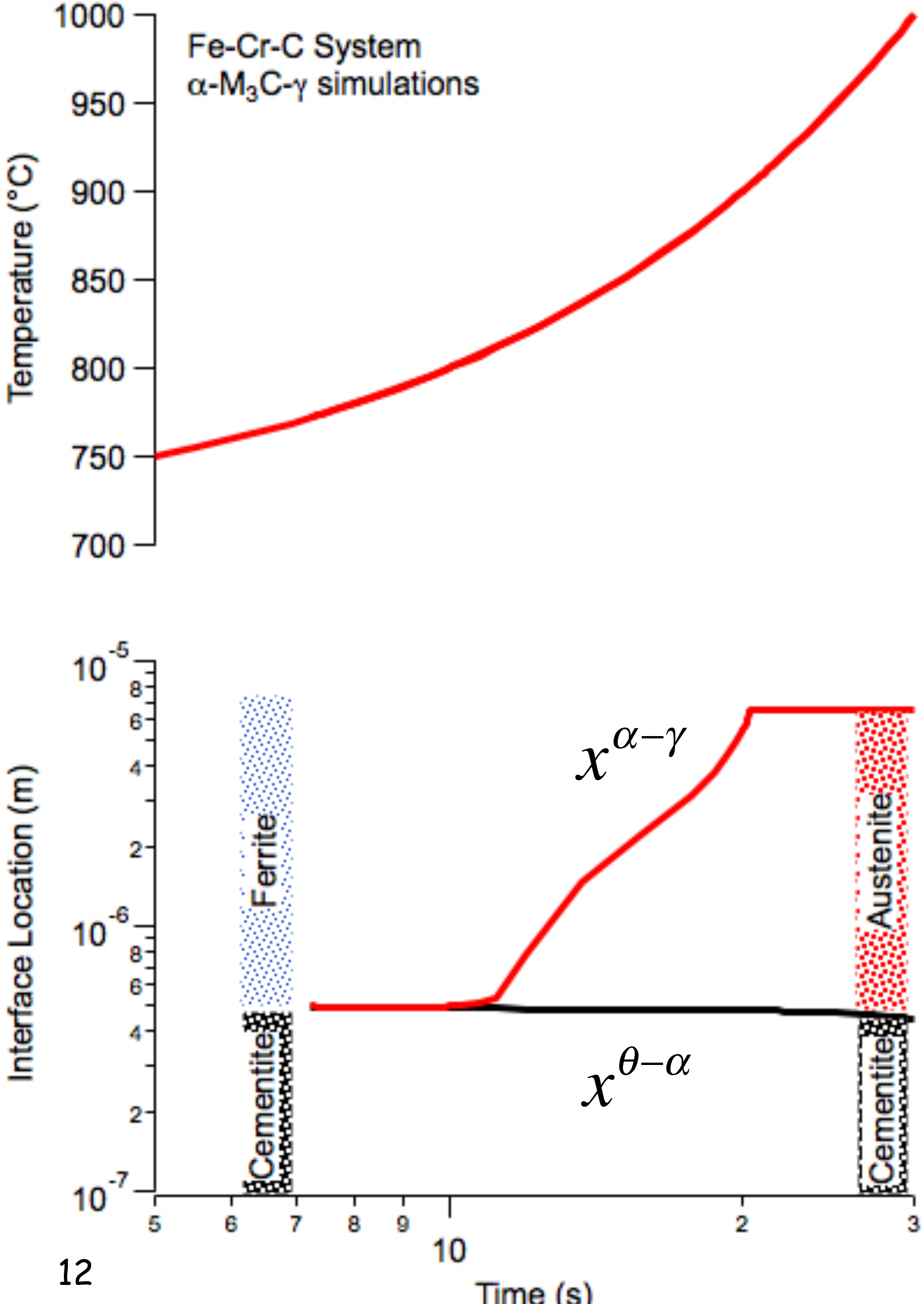
- Dissolution of cementite in α-ferrite followed by growth of austenite into ferrite
- Let us compare the same with higher heating rates.





Simulations for α-γ-Fe_3C Heating Rates: 10 & 100 °C/s

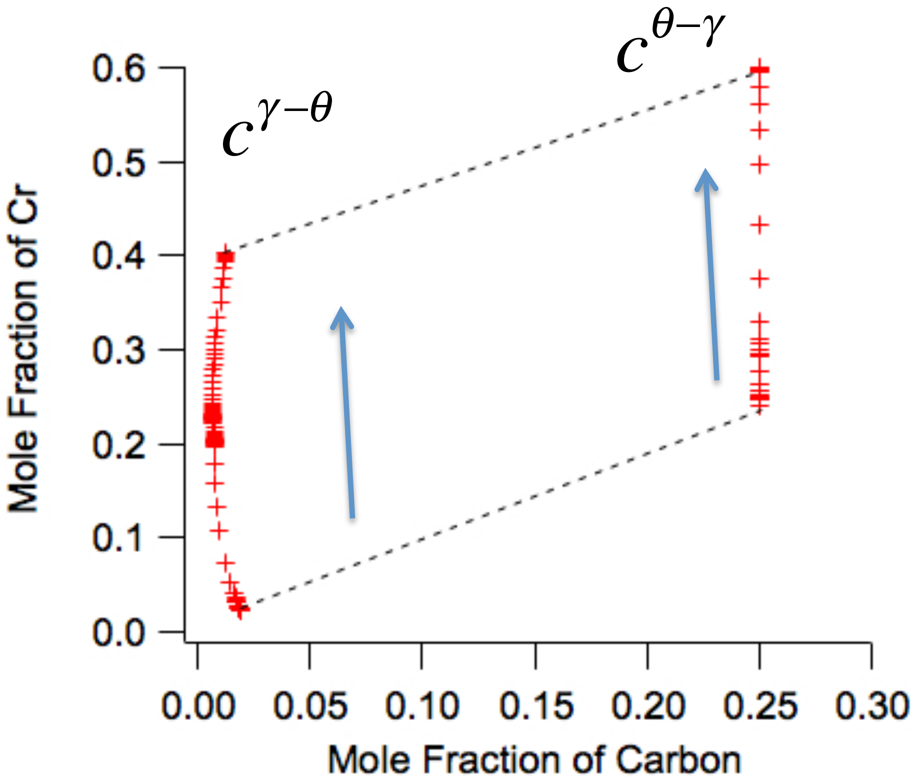
- Dissolution of cementite in α-ferrite and then growth of austenite into ferrite in all heating rates
- Austenite grows into both ferrite and cementite
- How does it compare with Fe-Cr-C system?

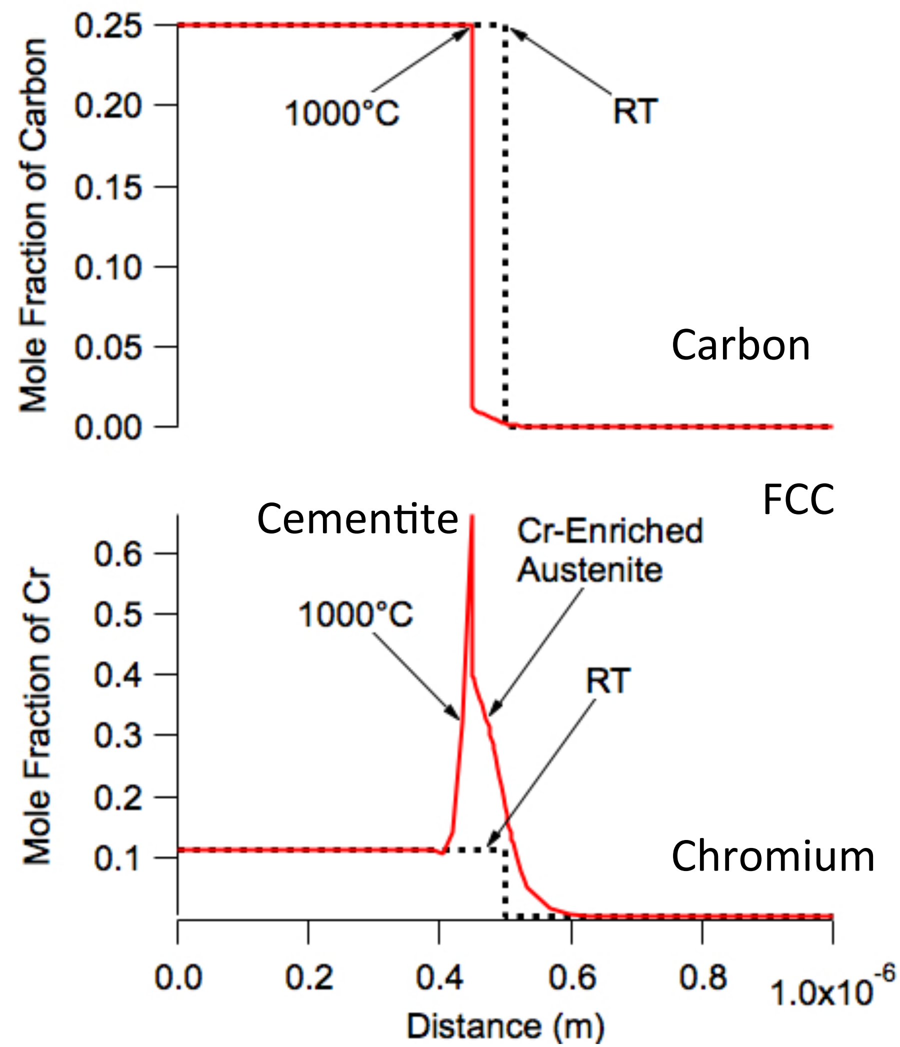


Calculations suggest sluggish dissolution of cementite that is enriched with Cr.

- Dissolution is sluggish even at 1°C/s.
- Carbon in austenite is expected to be lower than bulk value.

Interface Velocity Controlled by Cr-diffusion

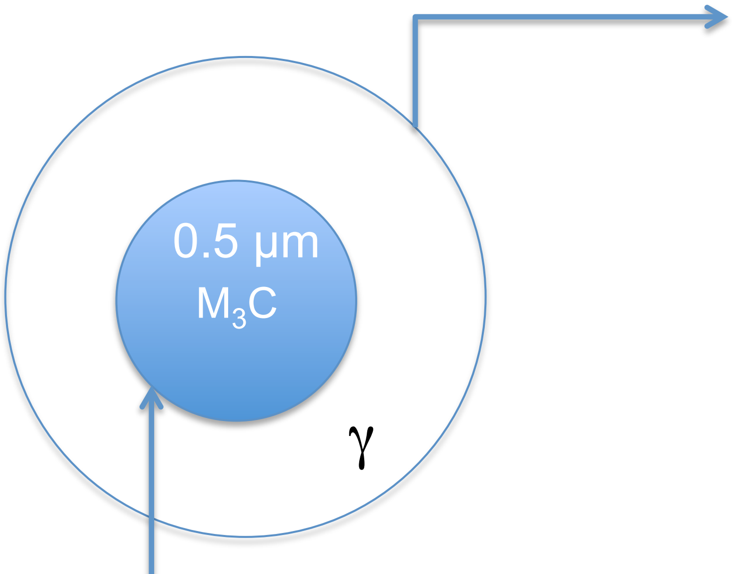




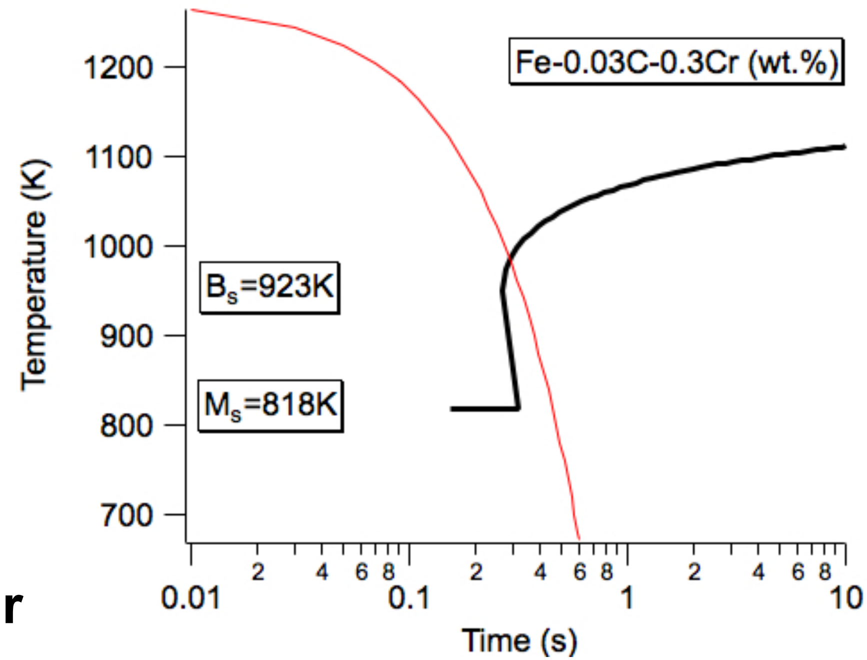
- Interface concentrations shift with temperature
- High-Cr Interface concentration at the cementite/austenite interface Cr-enriched austenite

Complex on-cooling transformations for austenite with carbon inhomogeneity

Fe - 0.01 to 0.03wt.%C and 0.33 wt.%Cr



Fe – 0.27wt.%C – 39.0 wt.%Cr



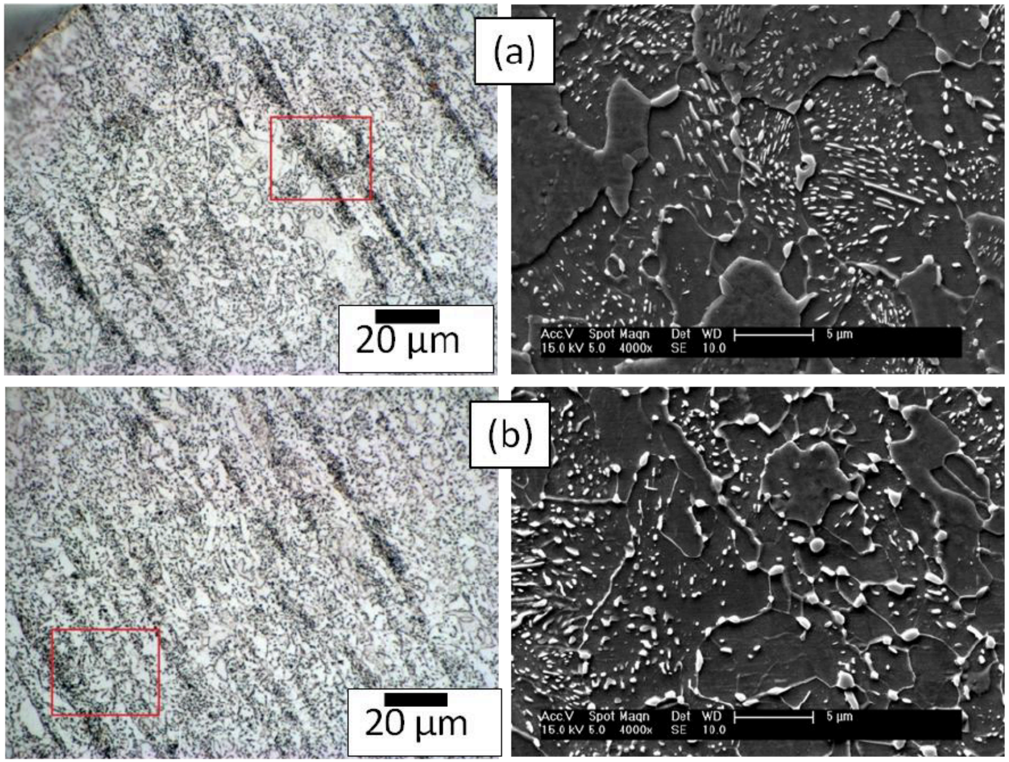
- Carbon-depleted austenite on rapid cooling can form mixed bainite and martensite.
- The Cr and C enriched austenite should transform to martensite! [T_0=730°C]

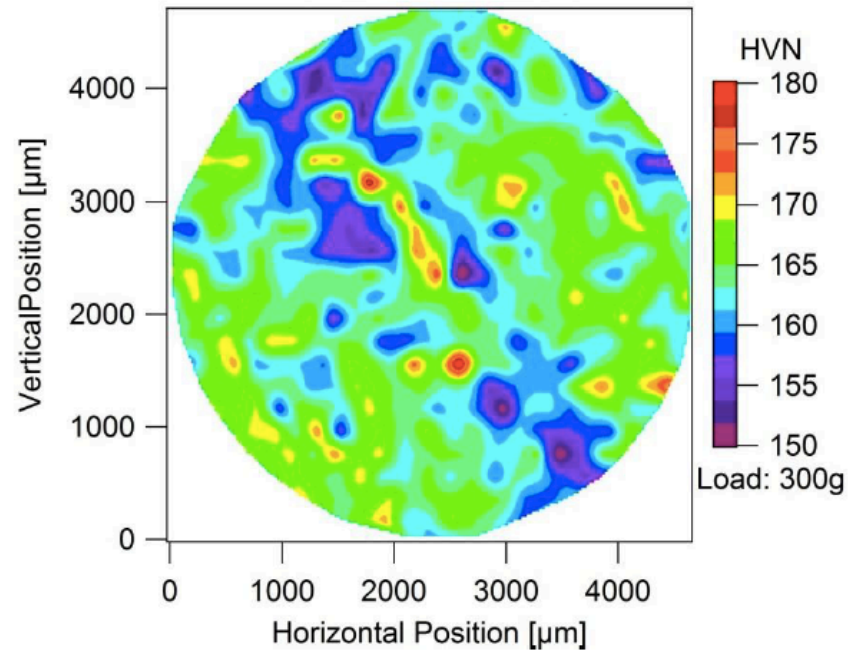
<u>Demonstration of concept</u>: Develop a competing armor steel using flash processing

- Goal: Design a flash processed steel and compare it with existing high hard steel
- Design Rules: (1) Spherodized steel; (2) Cr-enriched cementite; (3) Flash Thermal cycle

Material	Fe	C	Si	Mn	Ni	Cr	Mo	V	Cu	W	Ti
High Hard (wt%)	Bal.	0.3	0.4	0.9	0.9	0.55	0.55	0.005	0.1	0.01	0.03
FP 4130 (wt%)	Bal.	0.3	0.2	0.5	0.015	0.88	0.17	0.005	0.03	0.003	0.008

Initial microstructure of 4130 steel contains spherodized carbides in a ferrite matrix.

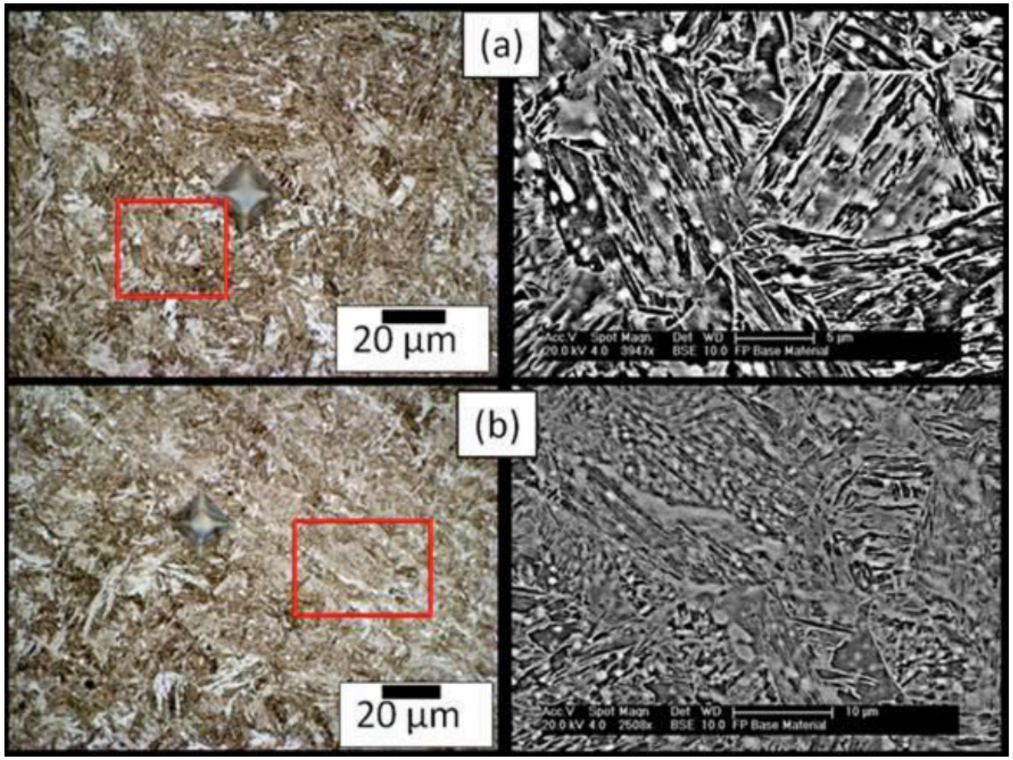


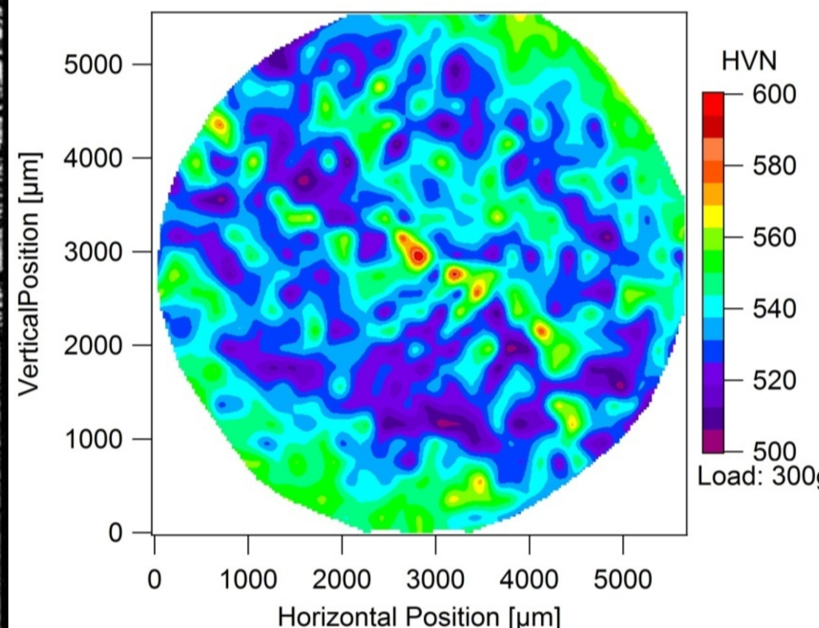


- Let us see how this microstructure changes on flash processing:

Spatial Distribution of Hardness

Mixed Martensitic and Bainitic microstructure was obtained.

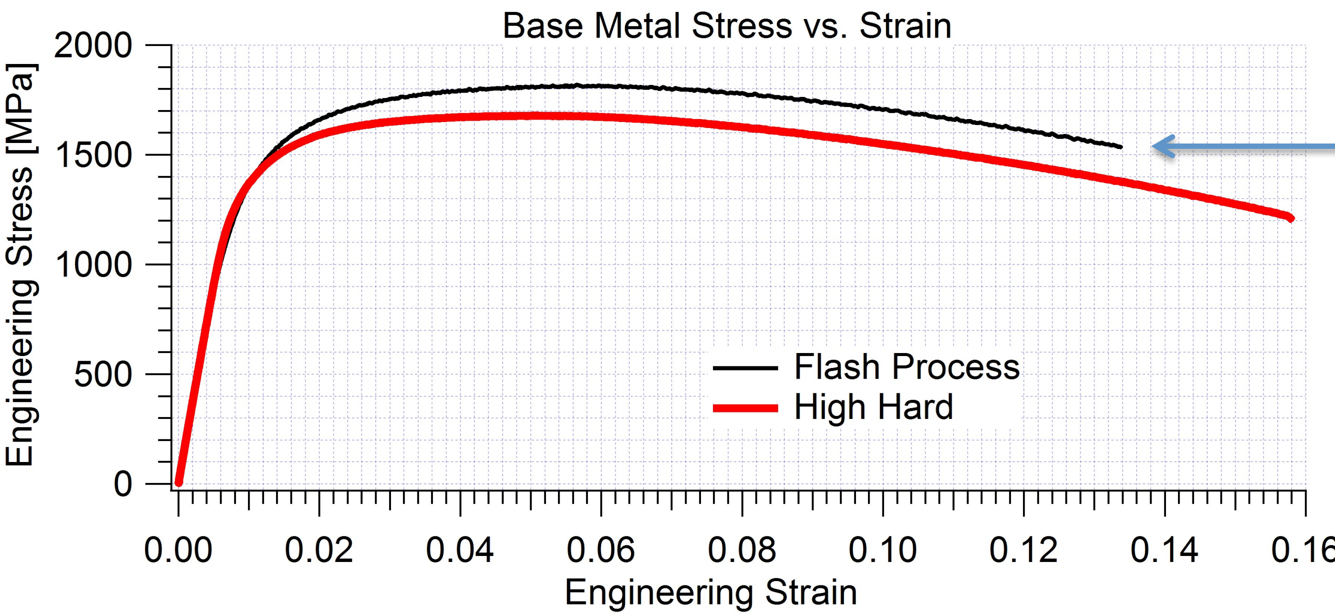




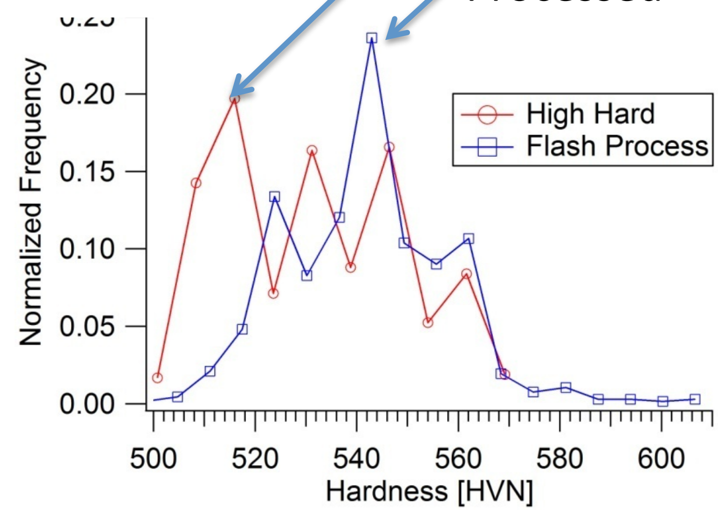
Spatial Distribution of Hardness

- Did we get good mechanical/ ballistic properties?

Flash Processed steels have high strength levels than that of high hard:

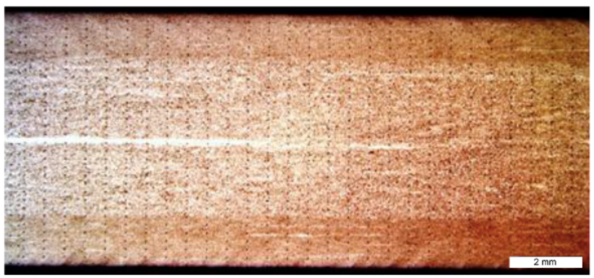


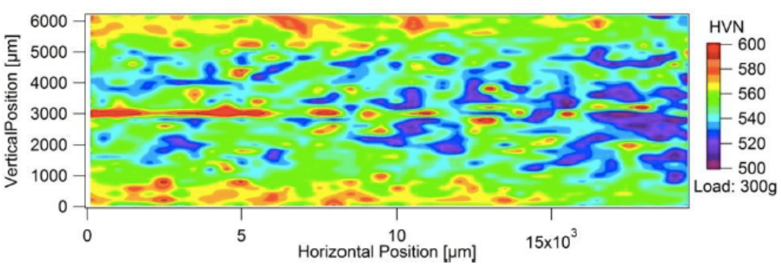
- Both High-hard and FP steels show through thickness hardness gradients



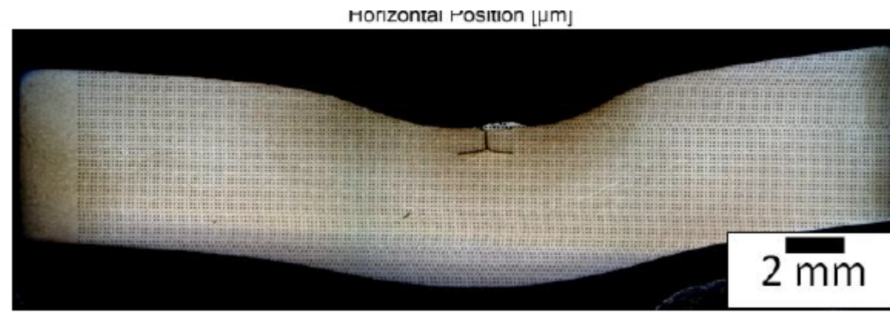
Irrespective of through thickness gradients, ballistic properties are good & better than existing armor steels.

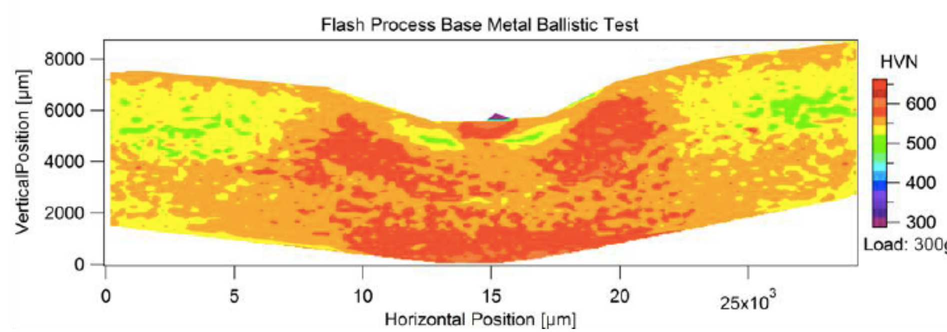
Before Impact





After Impact





- <u>Significance and Innovation</u>: Design initial macro- and micro-scale compositional/microstructure gradients before flash processing to engineer the properties

Armor Requirements : Lightweight, Performance, Operational Sustainability and Survivability

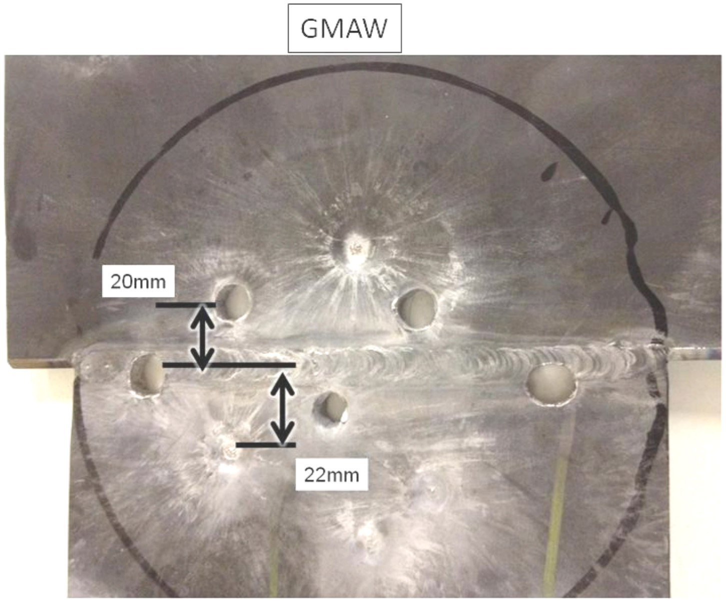
- FP steel has better ballistic protection per pound than currently available materials (steel, aluminum, and titanium)
- <u>In order to fully deploy flash processed steel, weldability must be addressed</u>

Figure 6. Machined Component made from ATI 500-MIL™ high hardness armor steel.

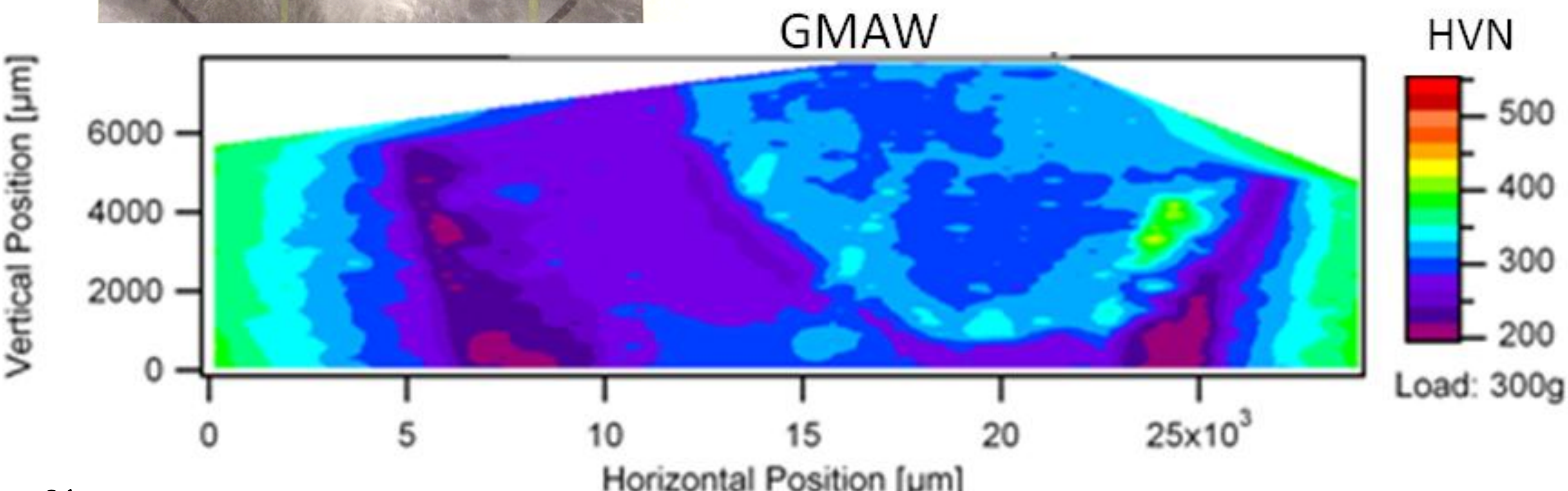
Figure 7. StrykShield situational awareness kit by Carapace Armor Technology made using ATI 500-MIL™ high hardness armor steel.

Figure 8. StrykShield situational awareness kit by Carapace Armor.

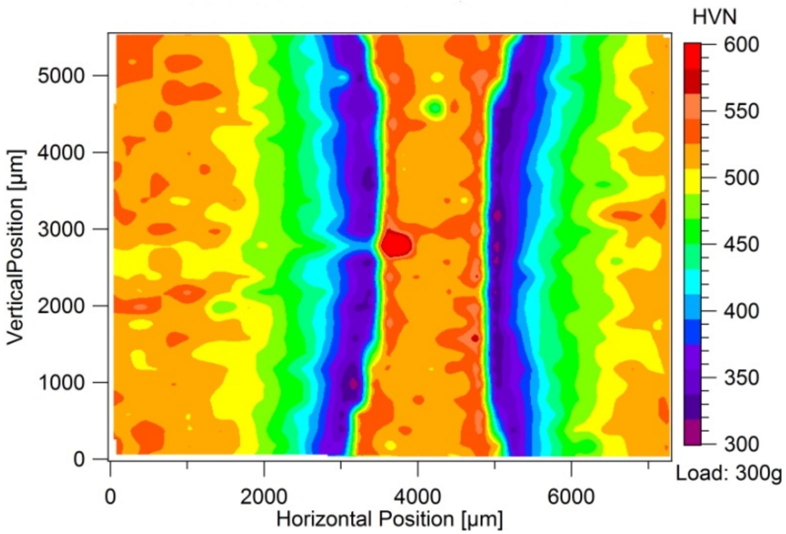
Gas metal arc welding leads to softening & bullet penetration in the weld and HAZ

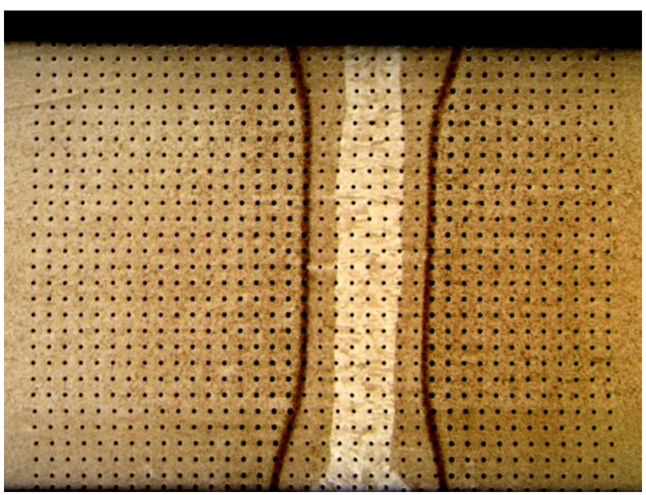


- Can we minimize the softening to mimic flash process thermal cycle during welding?

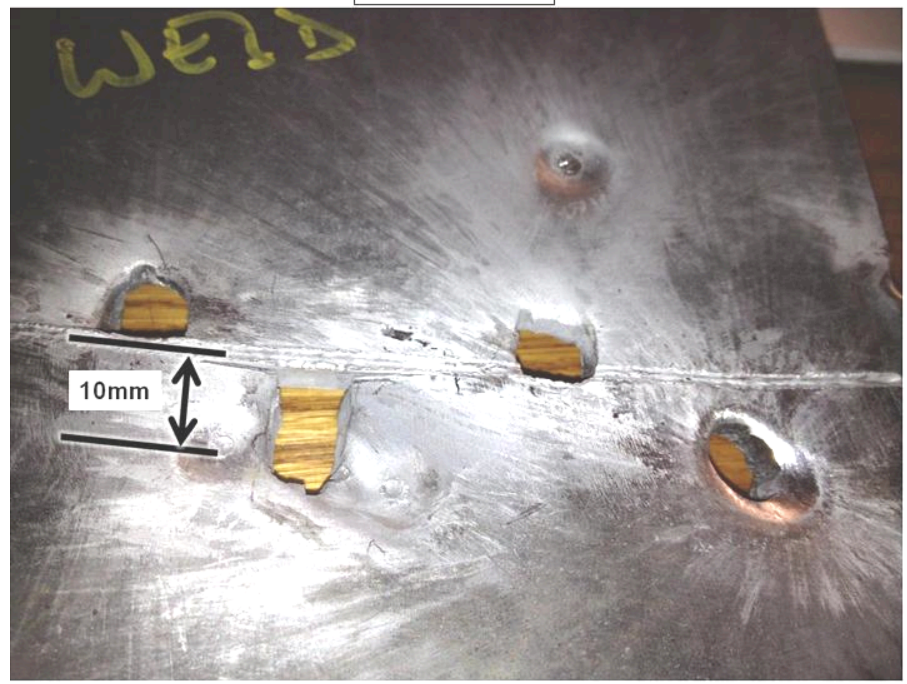


Using laser welding, extent of softening and vulnerability during ballistic testing was reduced



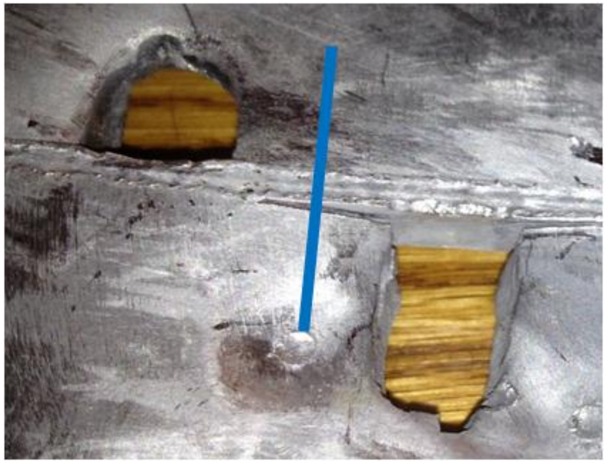


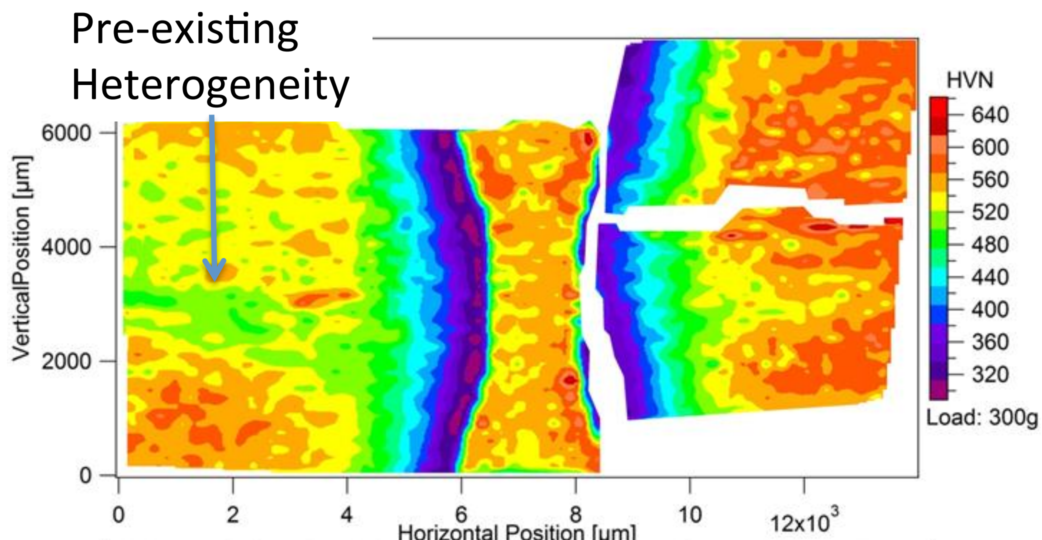
Laser Weld

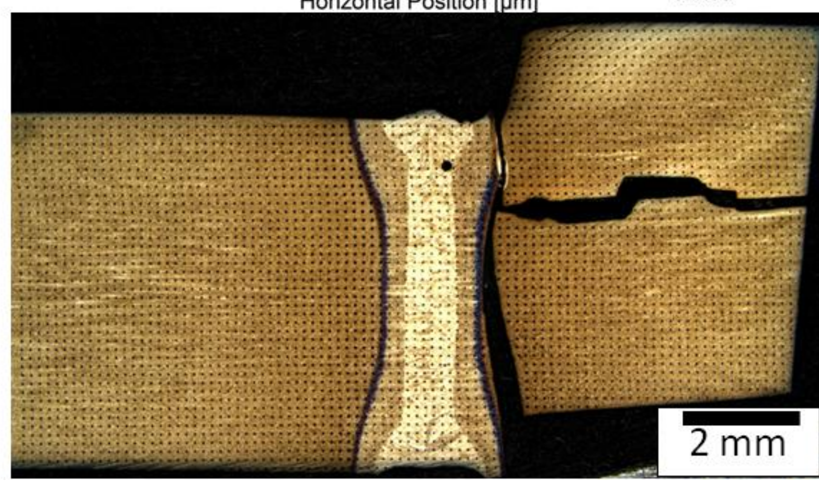


- How did the crack propagation occur under ballistic testing?

FP steel laser weld provides unique crack propagation characteristics







- Banding in the initial flash processed microstructure is attributed as the reason for such failures
- Future Research: Designing such microstructure through control of initial microstructure before flash processing

Conclusions

- What did we find?
  - Mixed microstructure containing bainite, martensite and un-dissolved carbides
  - Good combination of strength, ductility, ballistic properties
  - Extent of softening can be reduced by laser welding
- What are the design rules?
  - Control of spherodized microstructure, macro and micro-scale compositional gradients before flash processing [Heating Rate, Hold Time, Quench Rate]
- What is the significance?
  - An alternative strategy for obtaining advanced high strength steels for wide range of applications