Flash® Bainite Process

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Acknowledgements:

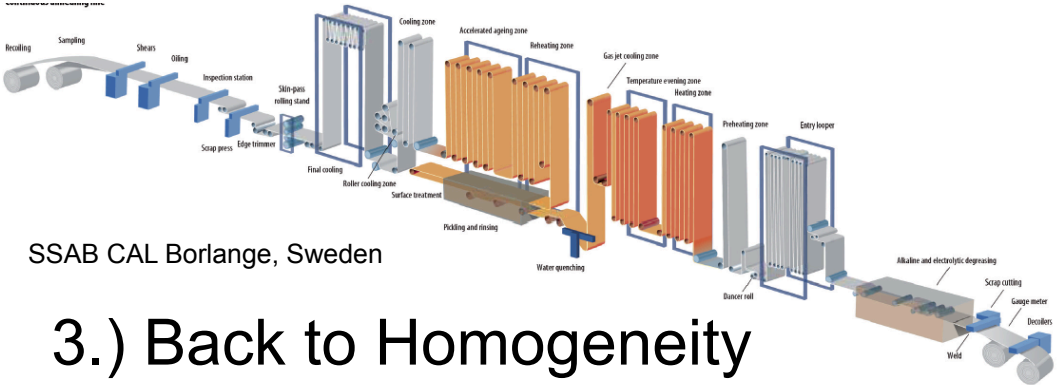
Ohio State University
CIMJSEA ~ NSF I/UCRC
Prof Suresh Babu & Team

Hyundai-Kia America Technical Center, Inc
Materials Development
Dr Alex Khutorsky

Unconventional Thoughts on Heat and Quench?

1.) Near Homogeneity

2.) Heterogeneity of Ferrite, Pearlite, and Carbides



SSAB CAL Borlange, Sweden

3.) Back to Homogeneity

But Why???

Heterogeneous complexity can lead to ~

"Maximum Strength" in Steel

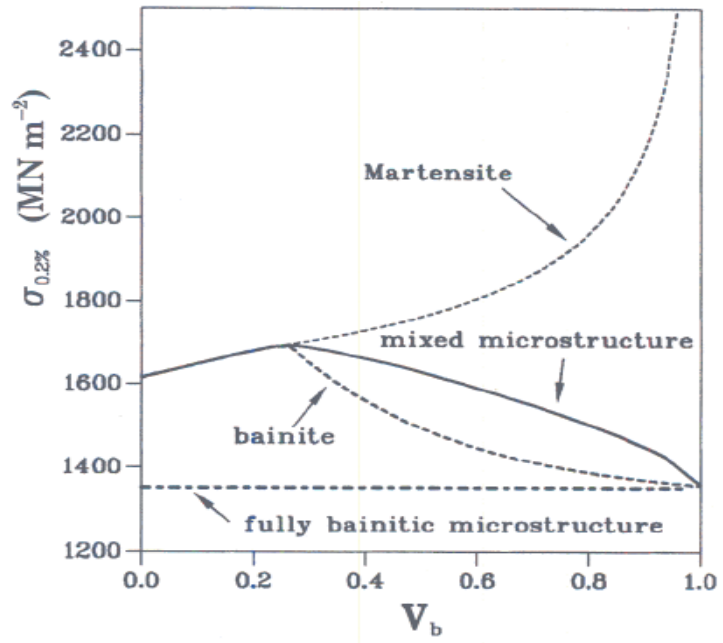
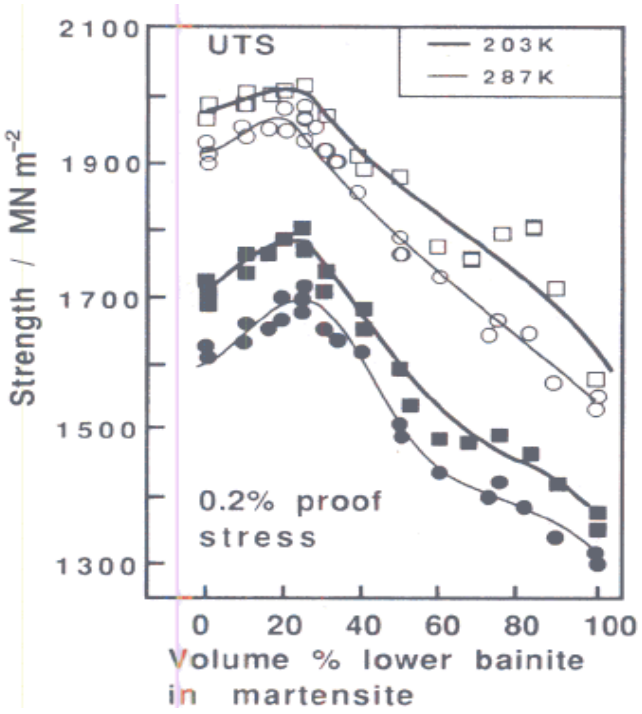


Illustration of contributions of bainite and martensite to overall strength of mixed microstructure

Research by: Tomita and Okabayashi

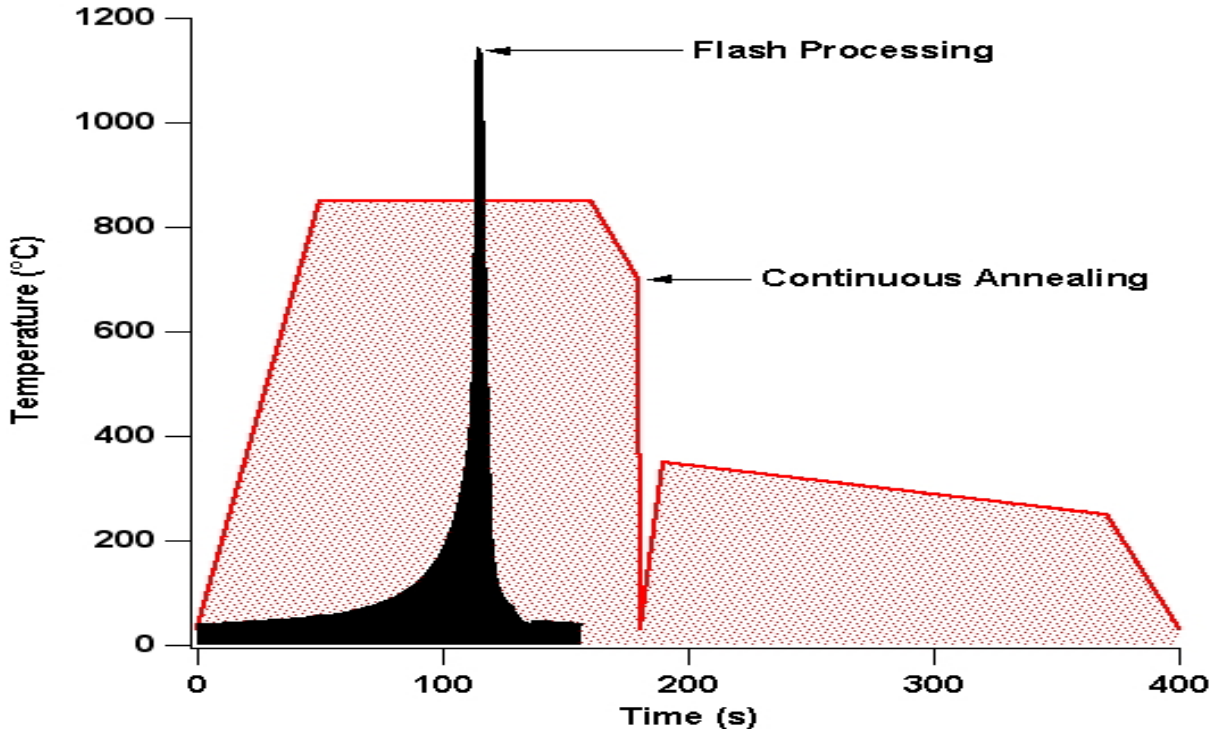


Young and Bhadeshia

It has been known for 30 years that ~20% Bainite and ~80% Martensite is stronger than ~100% Martensite

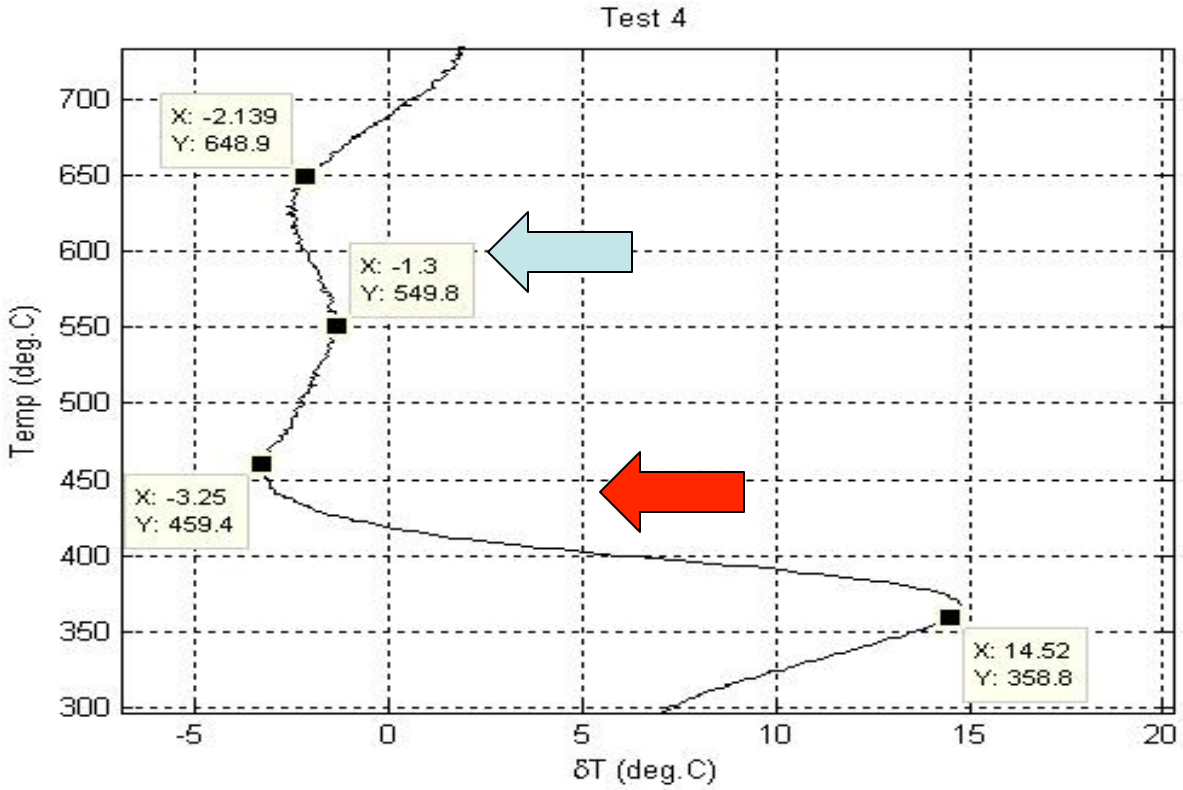
Flash® Bainite . . .

Extreme Thermal Cycling



- Temporal limiting of carbon migration and carbide dissolution
- High intensity energy input for controlled austenite growth
- Briefly elevated A3 due to volume fraction of ~0%wt C ferrite
- Heterogeneous austenite quenched w/ high driving forces

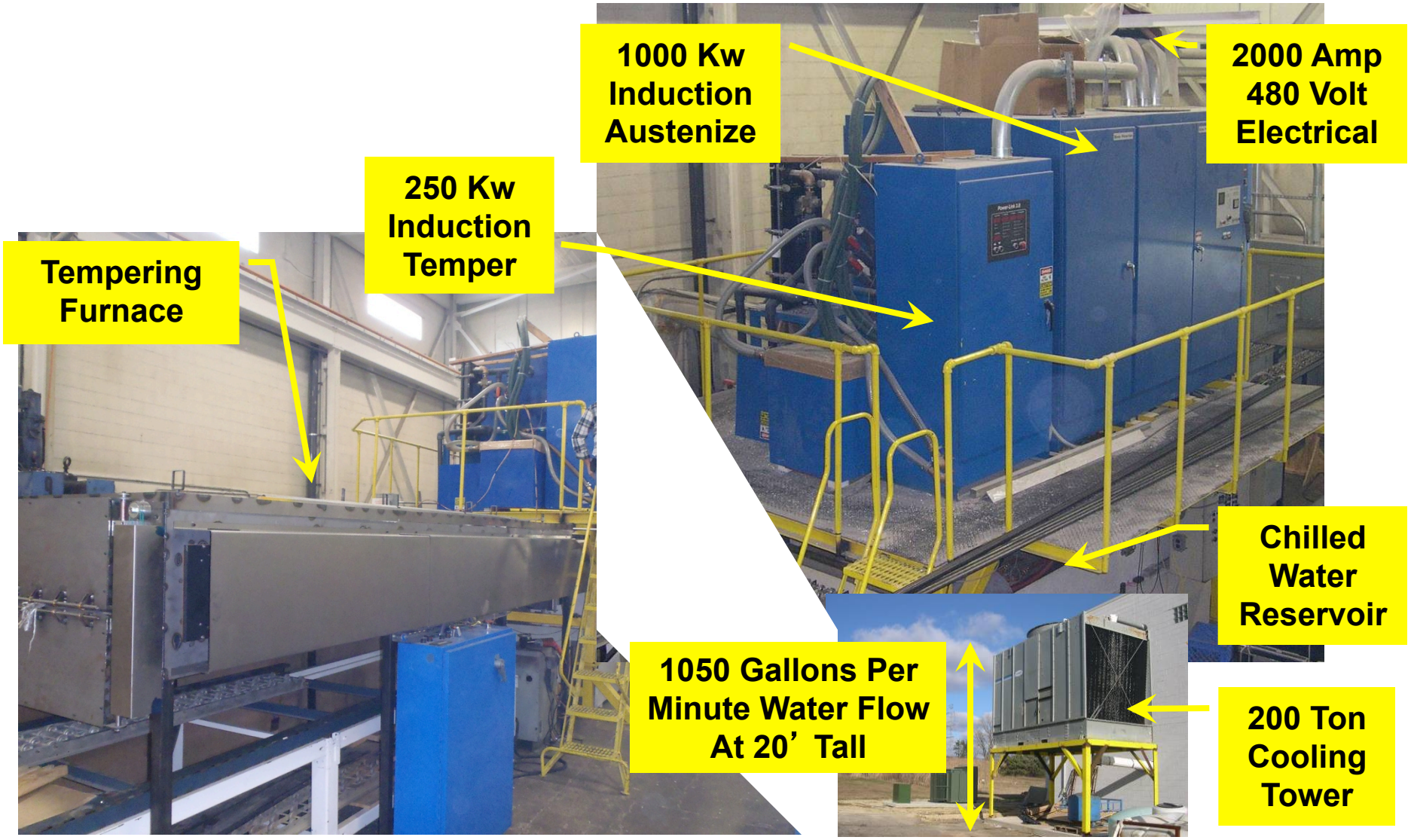
SSDTA® Analyses Shows Transformations at 649º ~ 550ºC and at 459º ~ 360ºC. Bainite and Martensite in <1s of quenching???



An Ohio State University team, led by Dr Suresh Babu, has developed transformation mechanisms explaining the presence of ~20% low carbon Bainite in a martensitic matrix laced with carbides (to be presented Day 3). Focus today is on Applications, both Civilian and Defense.

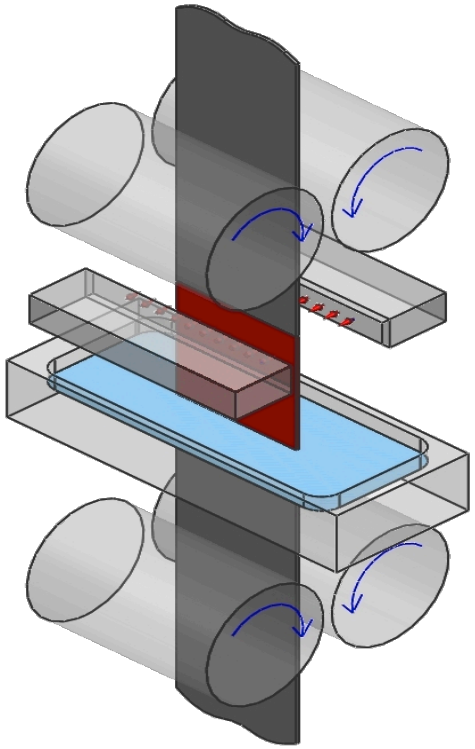
Flash® Bainite Pilot Line

Operational since July 2012 transforming 22 to 24kg per minute



Current 6.6mm x 61cm x 3m panels are FLAT within 1.2mm

Why consider
Flash® Bainite Processing?



… a method to heat treat heterogeneous steel to achieve ~20% Bainite, ~80% Martensite, and carbides in less than 10 seconds

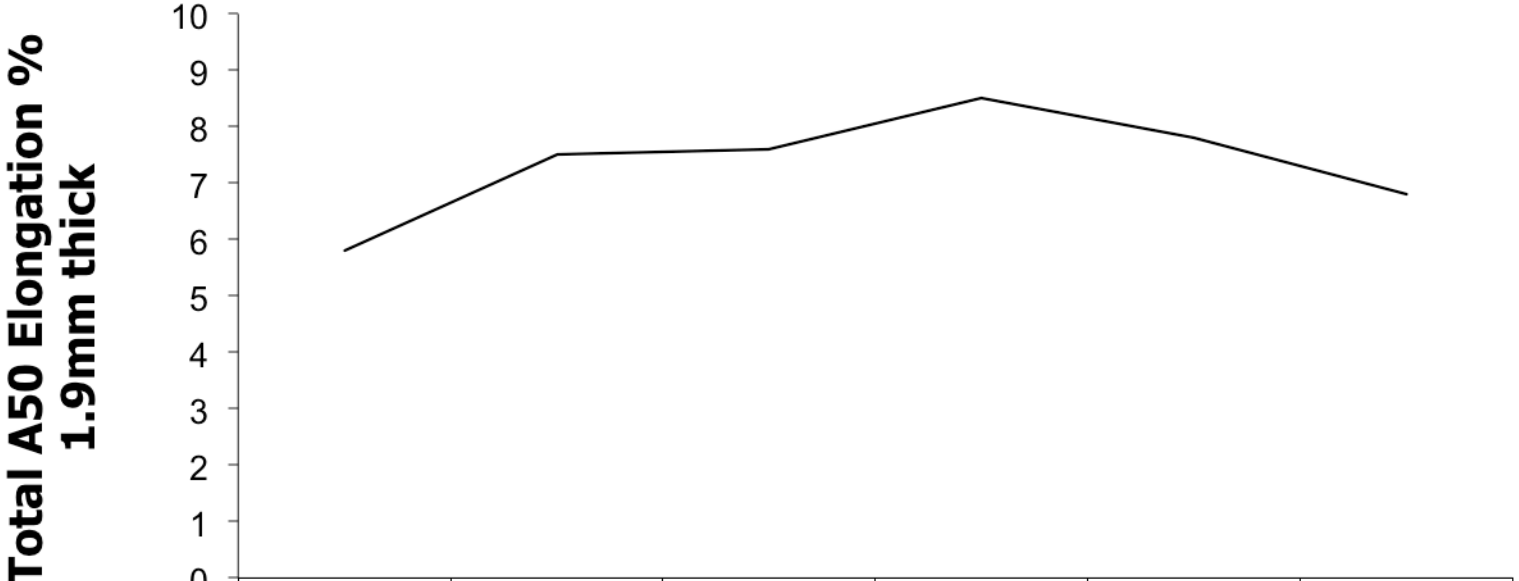
… a Pilot production proven, 21st Century variant on the heat and quench method to yield a ***Maximum Strength*** microstructure.

… An inexpensive, rapid ***Process*** proven to improve the mechanical performance of Sheet, Plate, and Tubing. Other 2-D cross sections like I-beams, C-channel, or angle iron are possible.

and

NOVELTY !!! (USPTO #8480824 of July 9, 2013)

Fully Strengthened Flash® AISI1010 Elongation VS Peak Flash Temp

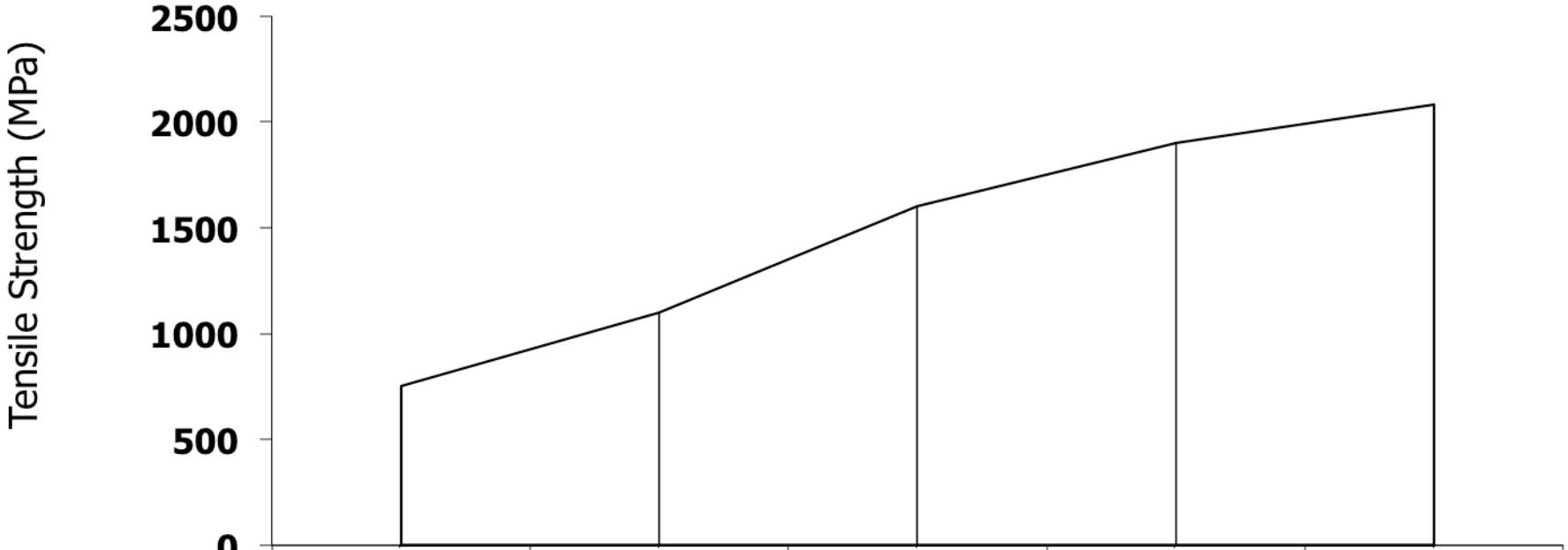


	1010ºC	1080ºC	1130ºC	1180ºC	1230ºC	1290ºC
Elongation %	5.8	7.5	7.6	8.5	7.8	6.8

- 1010ºC Peak Temp had 720MPa yield with 900MPa UTS
- 1080º-1290ºC Peak had 900MPa Yield with1100MPa UTS

- Flash® heating to peak temperatures far exceeding typical 800-950°C furnace and induction temps develops notably higher tensile strength
- Highest elongation found at larger “just right” grain size from 1180°C
- 1100MPa UTS at 8.5% Total Elongation ~ ***1.9mm Lean DP1000 ???***

Fully Hardened Flash® Bainite Carbon - Strength Relationship



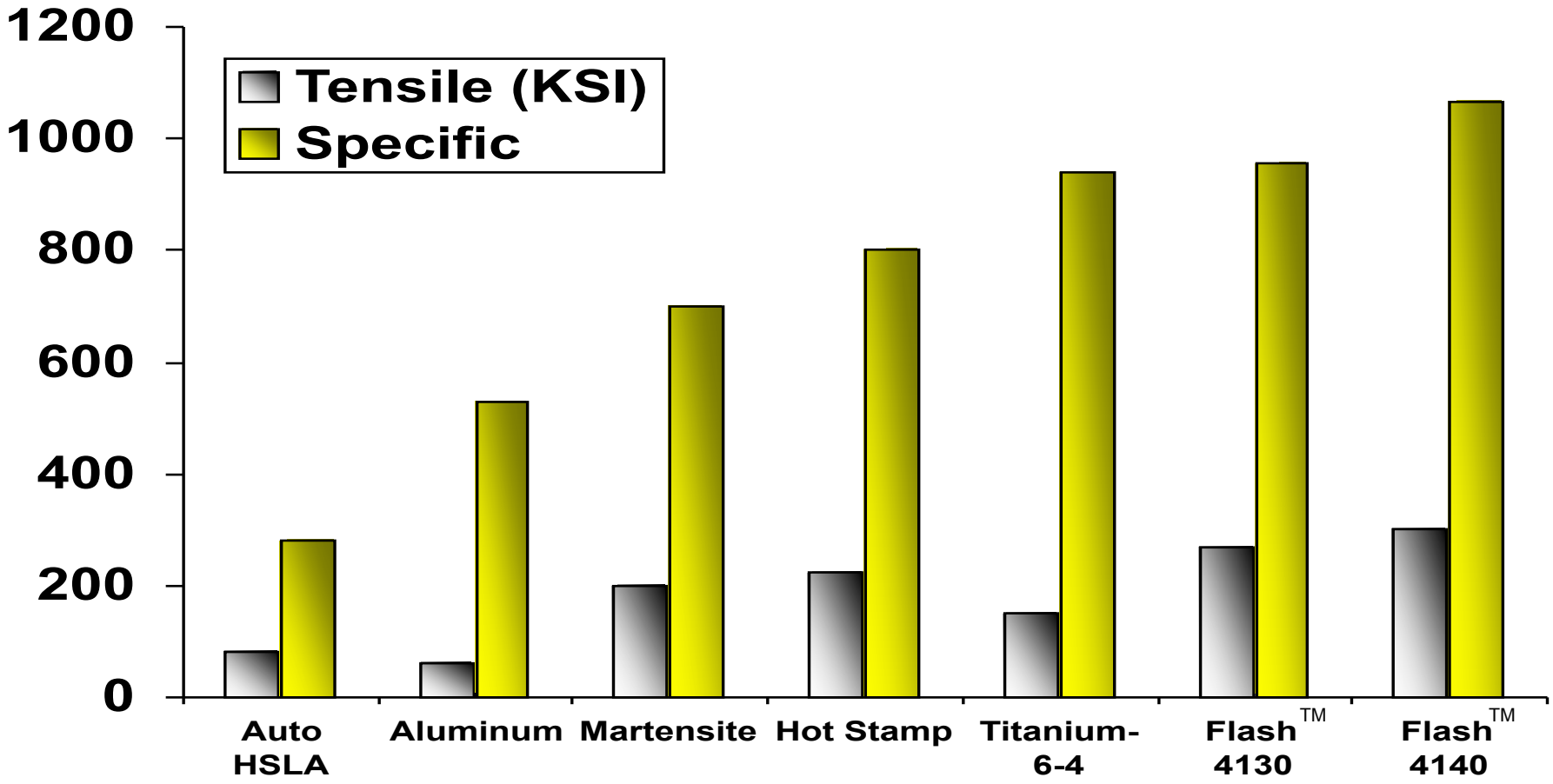
	AISI1004	AISI1010	AISI1020	AISI4130**	AISI4140**
Tensile (MPa)	750	1100	1600	1900	2080
Elongation A50	8.60%	8.50%	9.50%	11.00%	10.00%
%wt Carbon	0.036	0.104	0.211	0.305	0.402
%wt Iron	99.5	99.4	98.4	97.6	97.2

**Tempered for <900s at <275C

Very High %wt Fe ~ minimal alloying required
75-80% Yield/Tensile Ratios: 1100 to 2100MPa

Why Steel?

Low Density <u>Does Not</u> Mean Lightweight



HSLA is not "high strength", Aluminum is NOT "lightweight", and ***Flash® Bainite is stronger / more ductile than Ti-64 STA Bar***

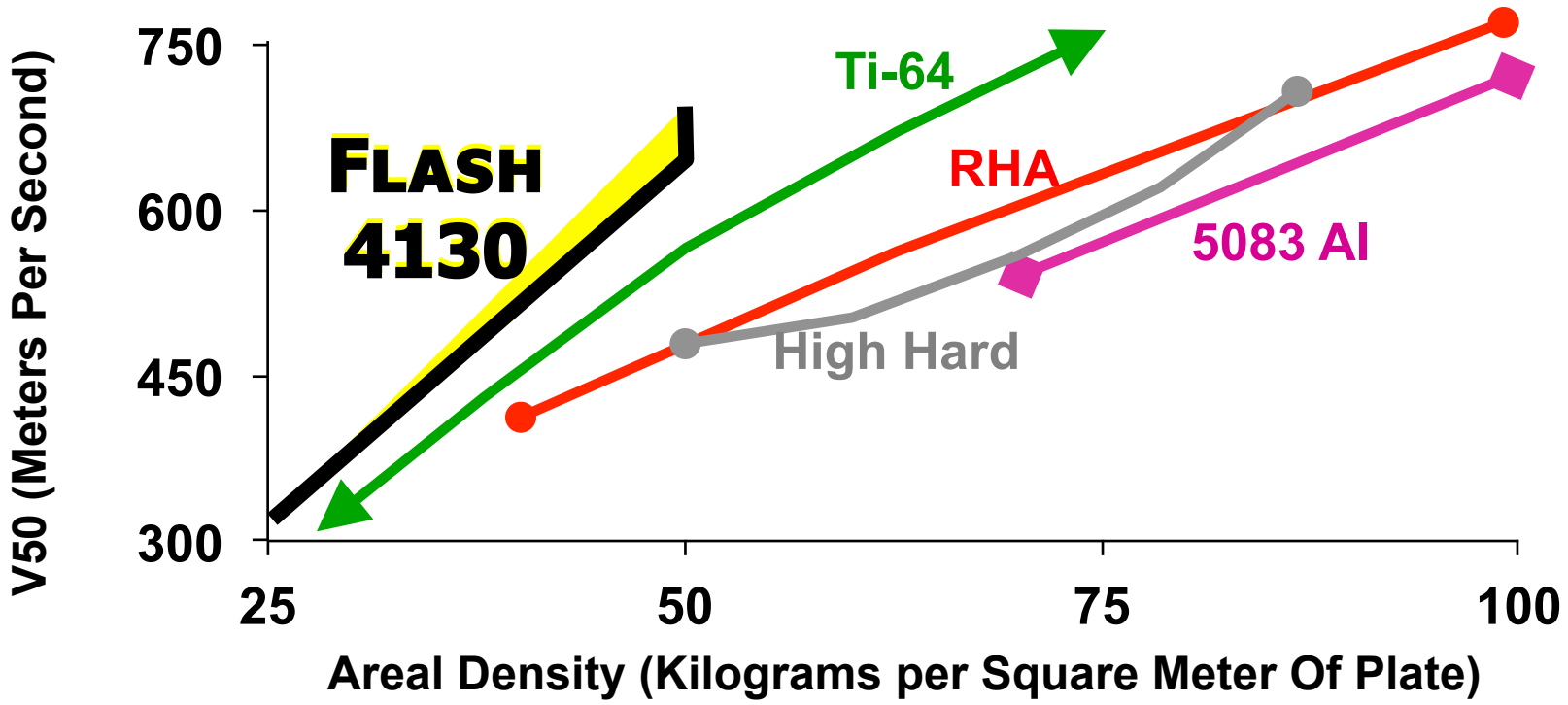
US Army Materiel Command Validation

US Army - ARDEC Technical Report of 22Feb2011 by Benet Labs / Picatinny Arsenal with ballistic data from US Army Aberdeen Test Center at the direction of US Army Research Lab:

"… the FB processing of 4130 steel demonstrates promise for applications needing a combination of high strength with good elongation, ductility and toughness (e.g. armor and vehicle). ***The novel FB process for steels has the potential to reduce product cost and weight while also enhancing mechanical performance.***"

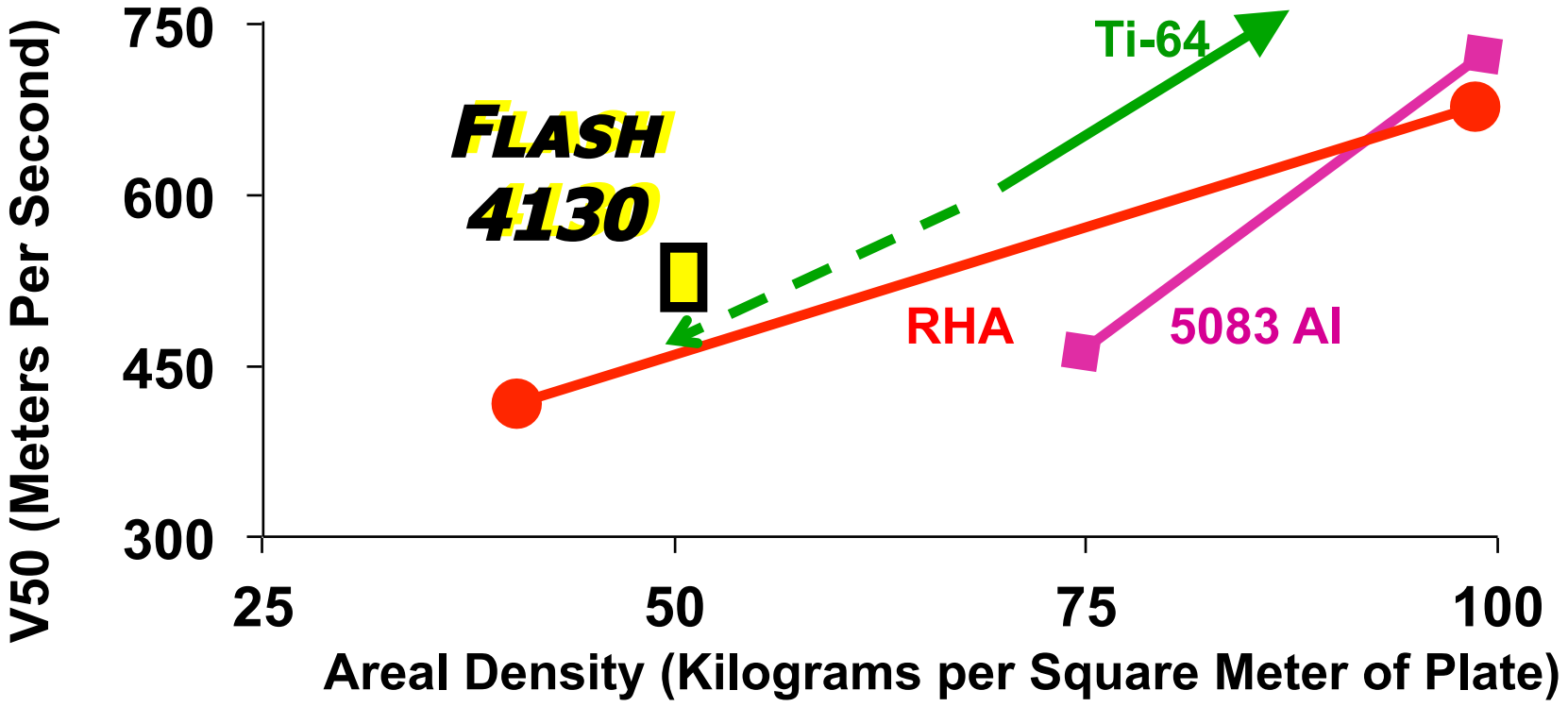
CRADA #ARL-13_04 is to test 600 Brinell Ultra Hard Armor

US Army-Aberdeen finds Flash® 4130 STOPS 0.30-cal Armor Piercing @ 0º Obliquity Better than . . .



- ◄ Titanium-64 Armor from MilDtl 46077F
- ● Rolled Homogeneous Steel Armor from ARL-RP-0089
- ● High Hard Steel from ARL Bulgarian Dual Hard Rpt
- ■ 5083 Aluminum from ARL-TR-4664

US Army-Aberdeen finds Flash® 4130 STOPS the 20mm Frag Simulating Penetrator @ 0º Obliquity Better than . . .



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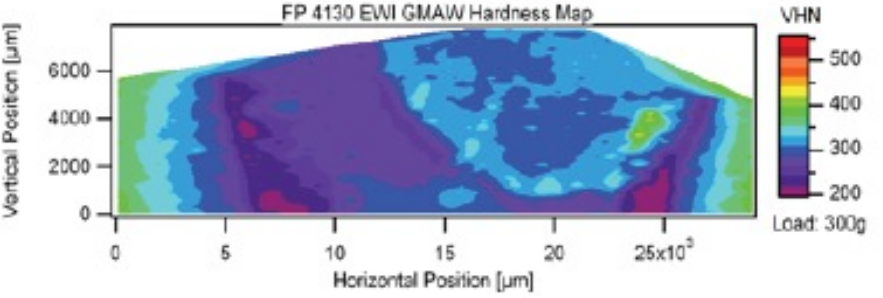
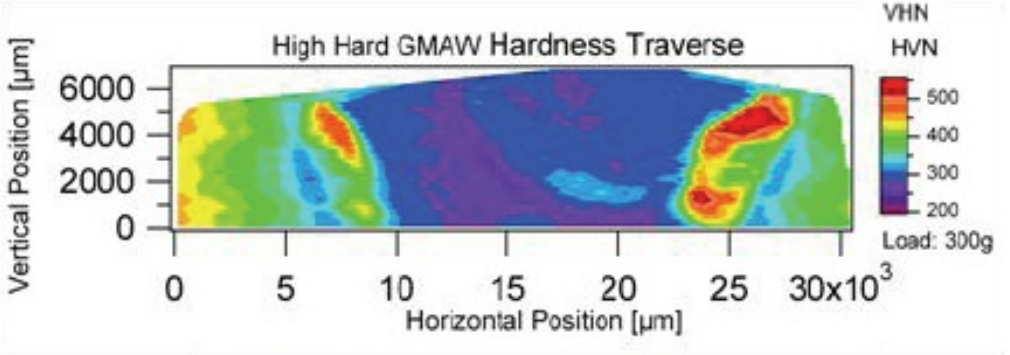
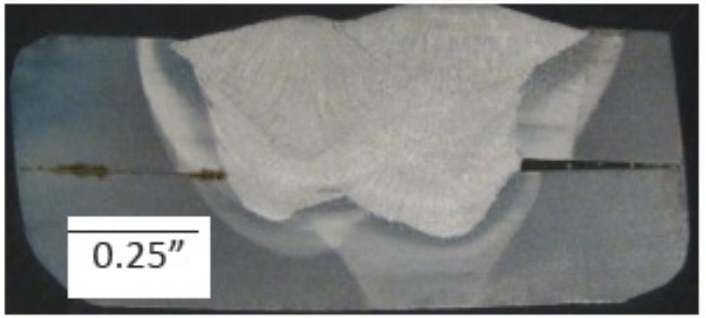
6 Pass GMAW Hardness Results

1. Both Flash® 4130 and High Hard have significant softening in HAZ.
2. Both HAZs are approx same width at same welding parameters.
3. Both steels have approx the same minimum hardness and strength.
4. The High Hard parent material transforms to brittle martensite adjacent to the final weld pass. The Flash® 4130 parent material adjacent the final weld pass is softer, thus more ductile.







Theory: Homogeneous 0.30%wt C and dissolved alloys lead to brittleness at the High Hard fusion line. Heterogeneous Flash® with very predominant lean chemistry (<AISI1020?) and low carbon bainite leads to more ductile weld.

Formable "Max Strength" Tubing
Flash® Bainite 4130

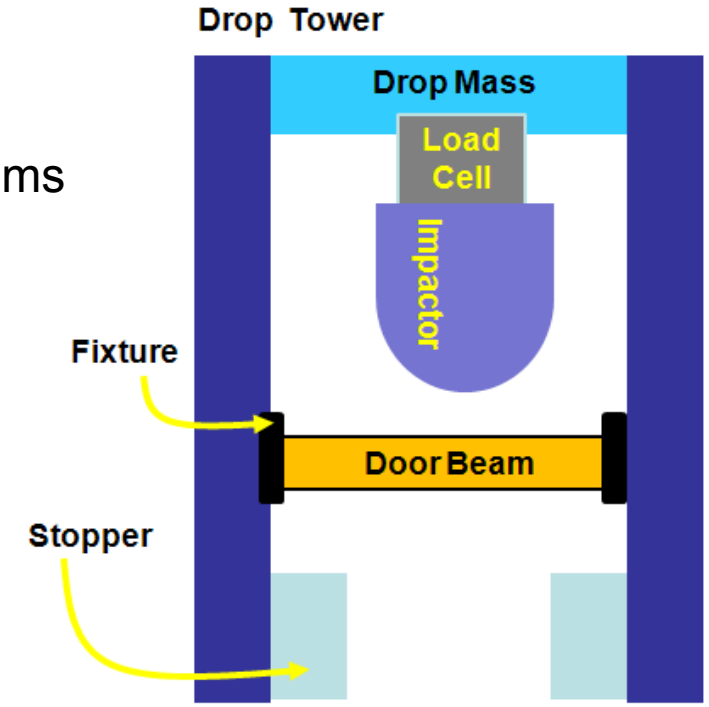
25mm Dia x 1.25mm Wall
80º Bend on a
125mm Centerline Radius

25mm Dia x 3.0mm Wall
180º Bend on a
67mm Centerline Radius

At >1800MPa with 10% elongation,
Flash® 4130 is triple the strength of "chrome-moly 4130"
and forms with NO outer diameter wall collapse

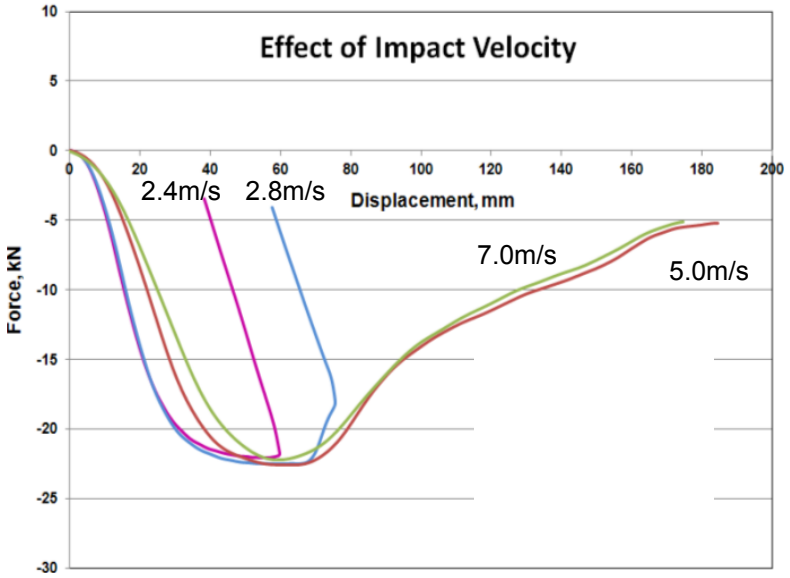
Vehicle Door Impact Beam - Drop Weight Test Concept

1. A component test methodology was developed
2. Intended to assess the performance of door beams under dynamic loading condition
3. Test Set-up objectives:
   - Correlation to the crash test data
   - Repeatability
   - Quantifiable output data
4. Output data
   - Force from Load Cell
   - Acceleration and velocity from accelerometers
   - Kinetic Energy $E = \frac{1}{2}MV^2$
   - Energy Absorbed to be calculated from
   - Force-Displacement curve
   - Stoppers are utilized to limit maximum displacement
   - Statistical sample – 2 test per condition

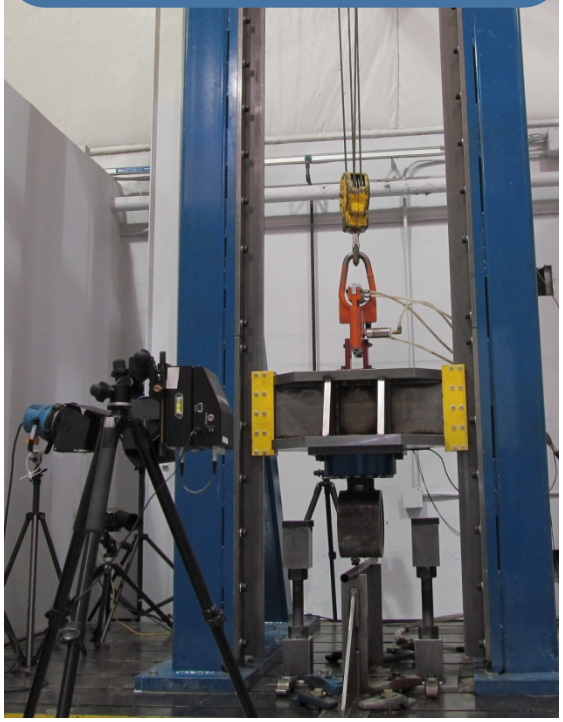


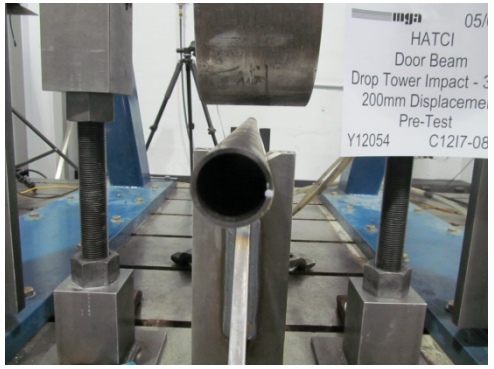
Drop Weight Test Parameters

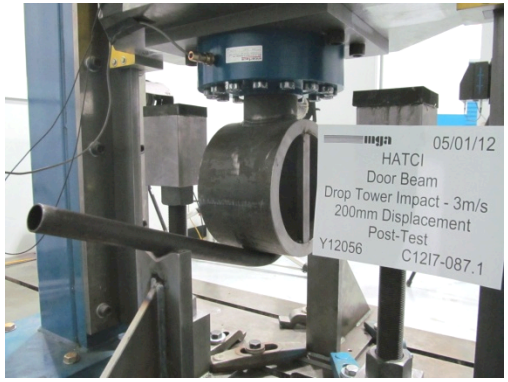
- The US side NCAP pole test was selected as a base in designing drop test parameters
- The impact velocity (energy input) and displacement limit were established so that every single test reached crack initiation stage.



Test Parameters:
Drop Mass – 320 Kgs
Impact Velocity – 5 m/s
Displacement Limit – 200 mm

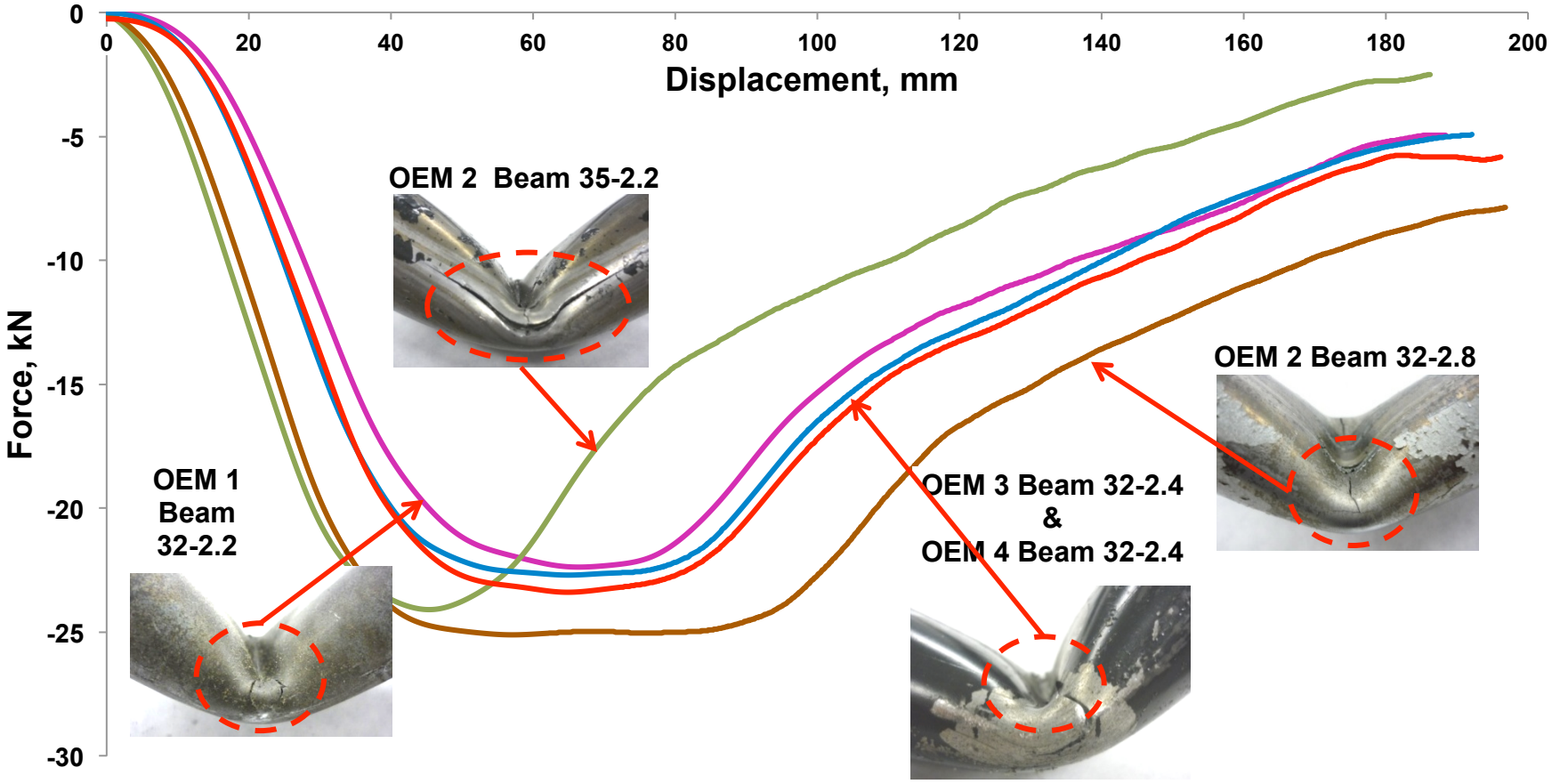




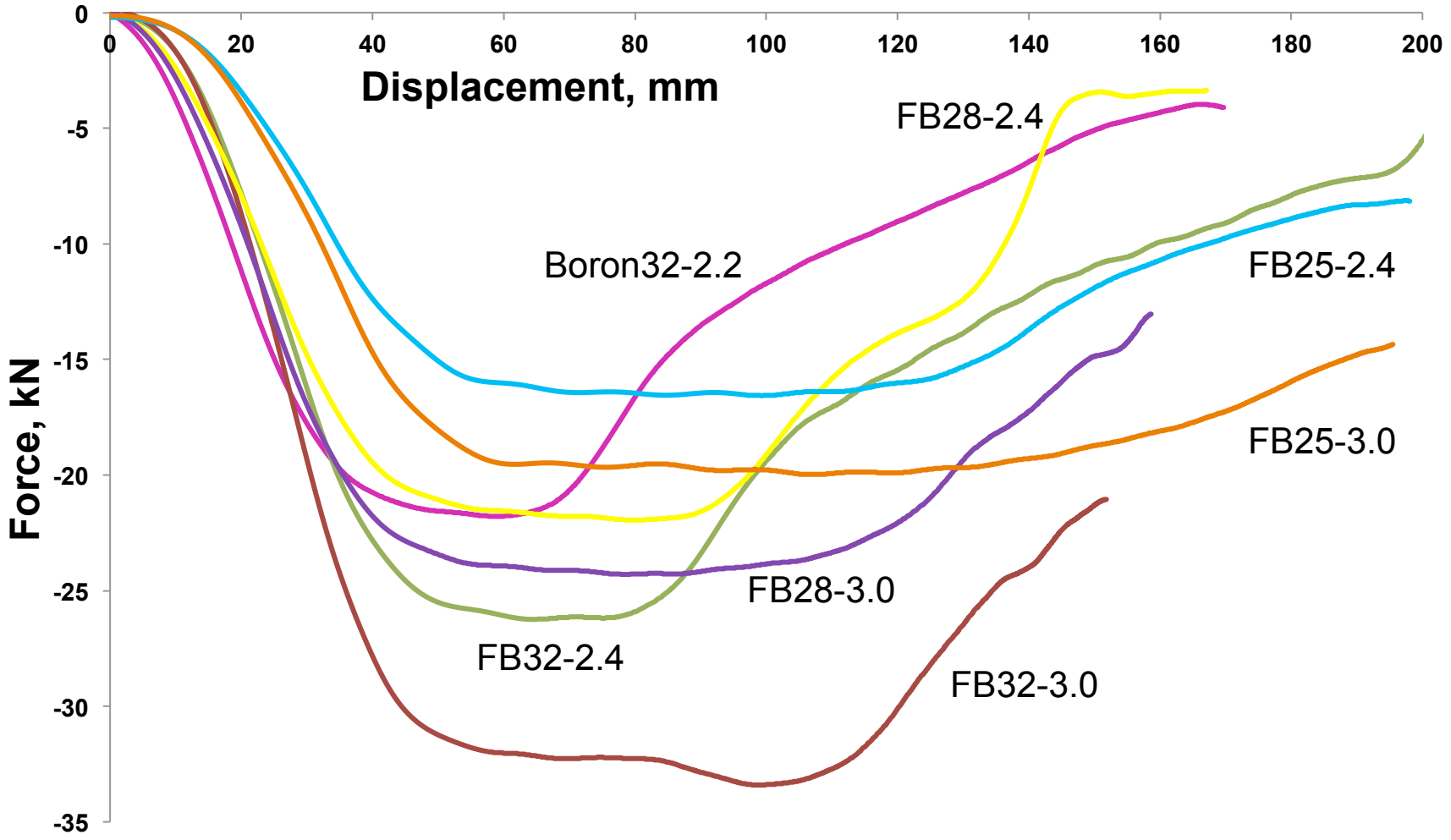


Performance of Competing OEM Door Beams

- ❑ Door Impact beams were taken from 5 highly rated current production vehicles
- ❑ All impact beams were boron hardenable steel from various Steel mills

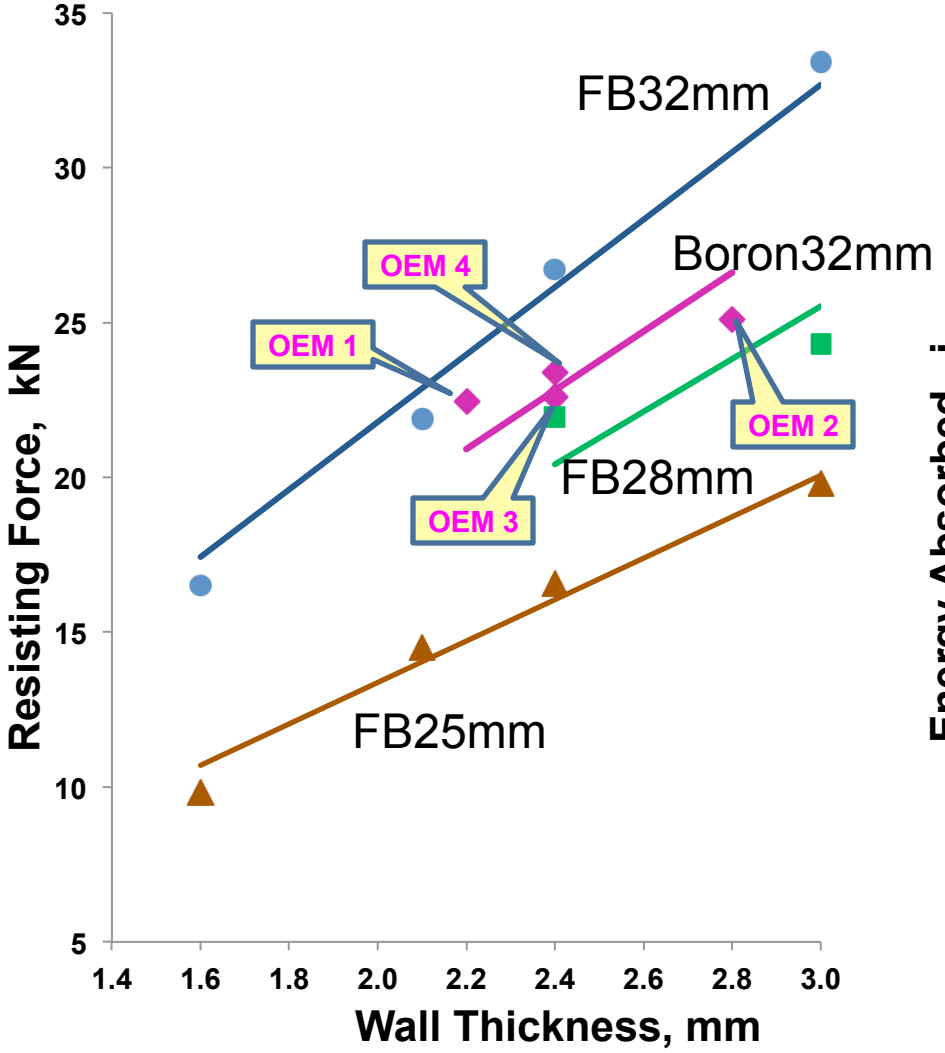


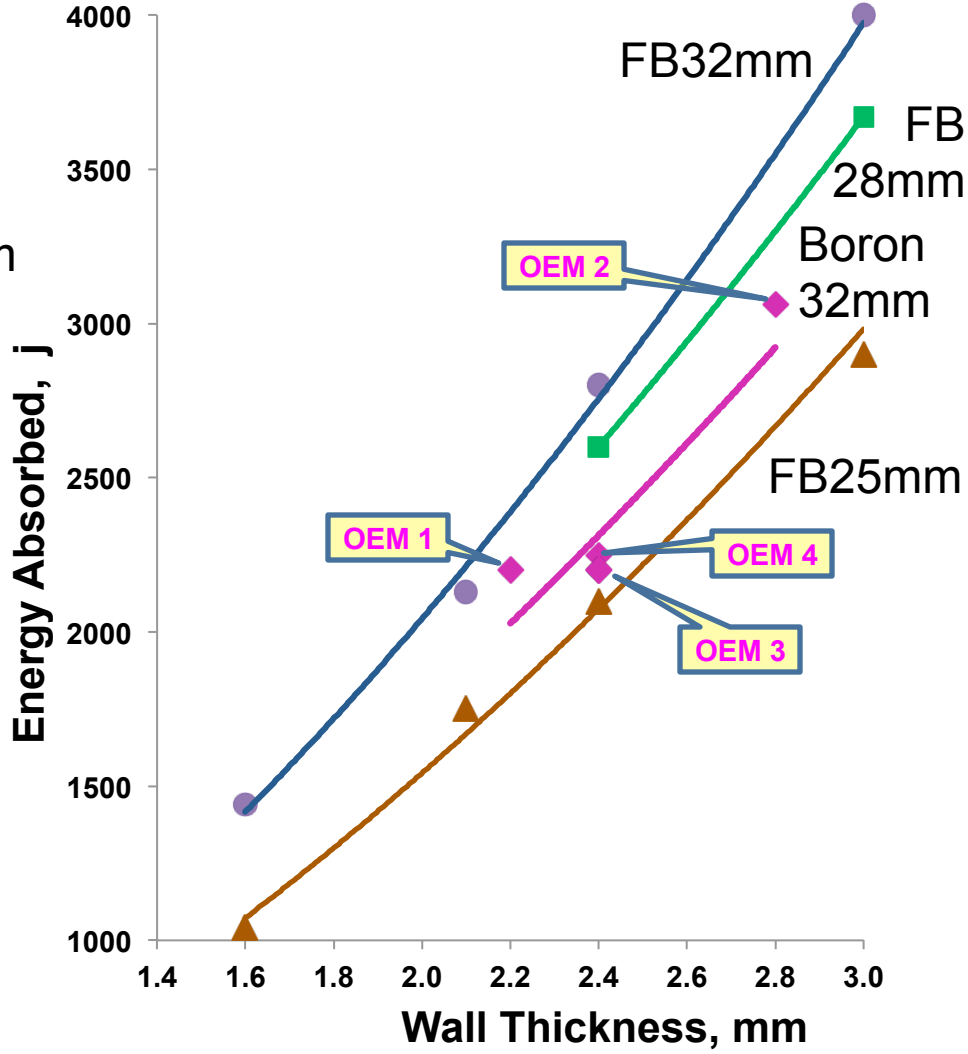
Effect of Flash® Bainite Tubing Diameter



- Larger Diameter Tubing trends toward higher Resisting Force
- Thicker Wall Stock trends toward higher total Energy Absorption

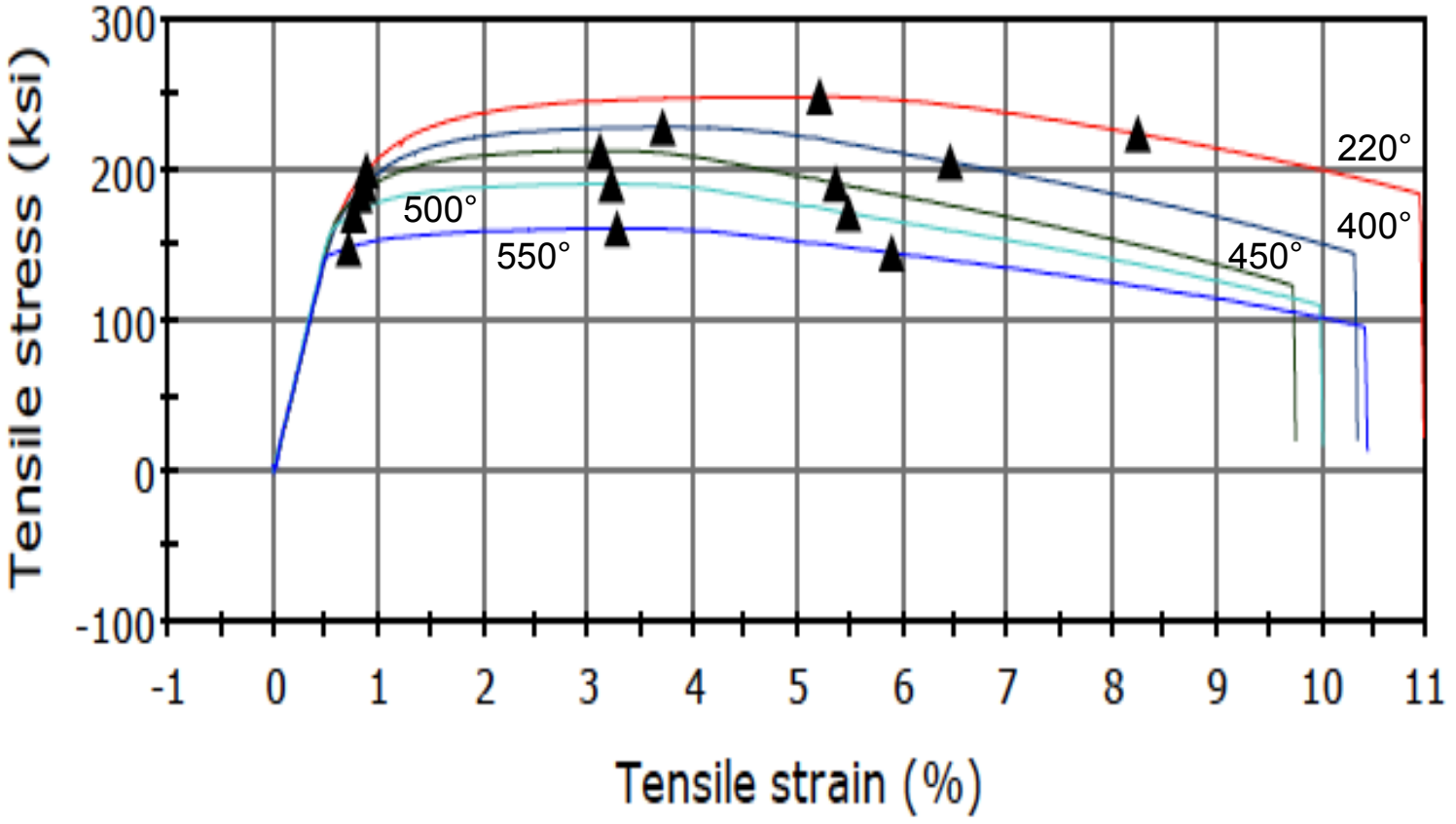
Flash® Bainite VS Boron Tubing . . . on a per mass basis





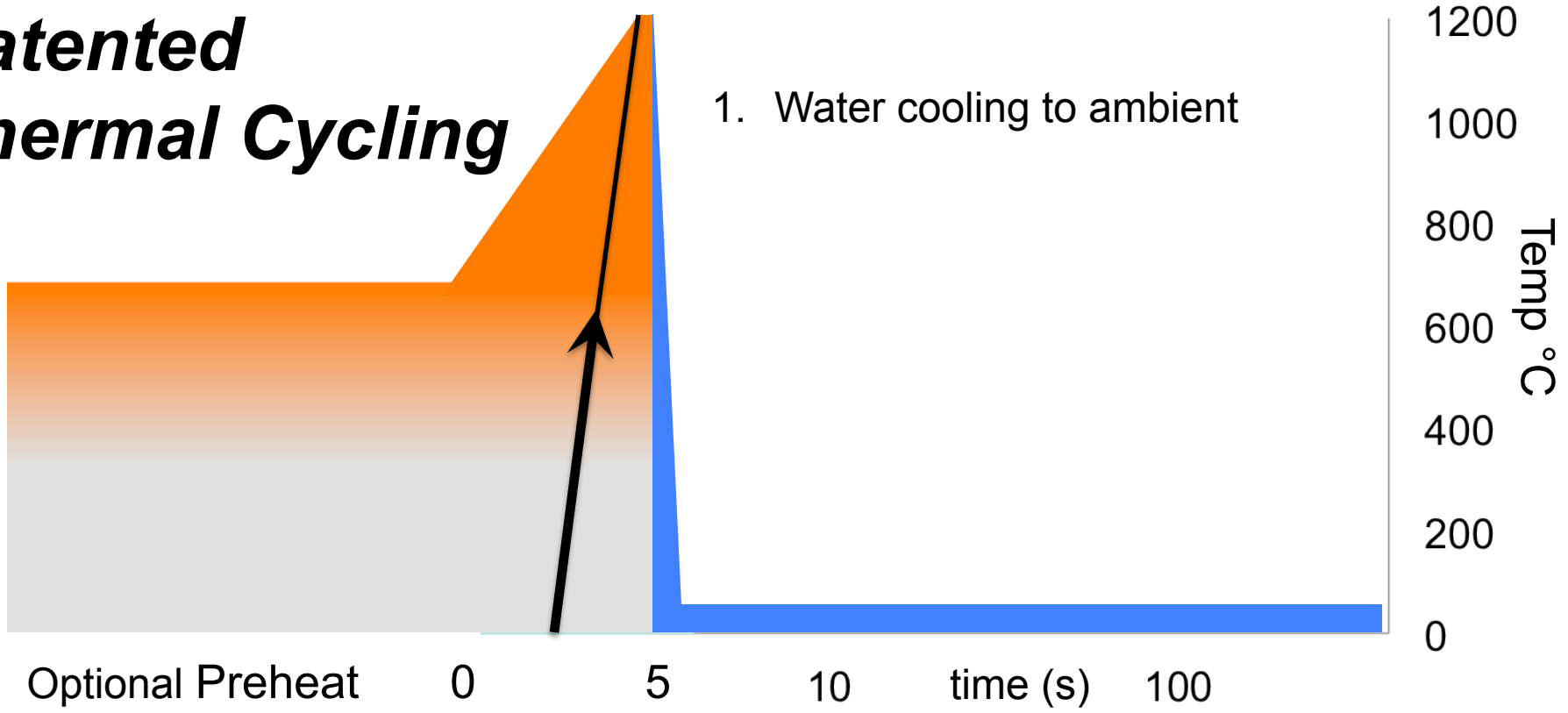
Flash® Tubing has ~15% higher Resisting Force and ~20% more Energy Absorbed than Boron Tubing

Flash® 4130 After Heating to … 400º-550ºC and Cooling to Ambient, Strength Remains



- Flash® 4130 at 400°C has 23% elongation. At 500°C, elongation is 30%.
- After cooling from 400°C, Flash® 4130 retains over 90% of its prior strength. 77% of UTS is retained after cooling from 500°C.
- **Hot Stamp Boron can be replaced by *"Warm Formed" Flash®4130* as a fully tempered, re-heatable "secondary operation" capable alternative**

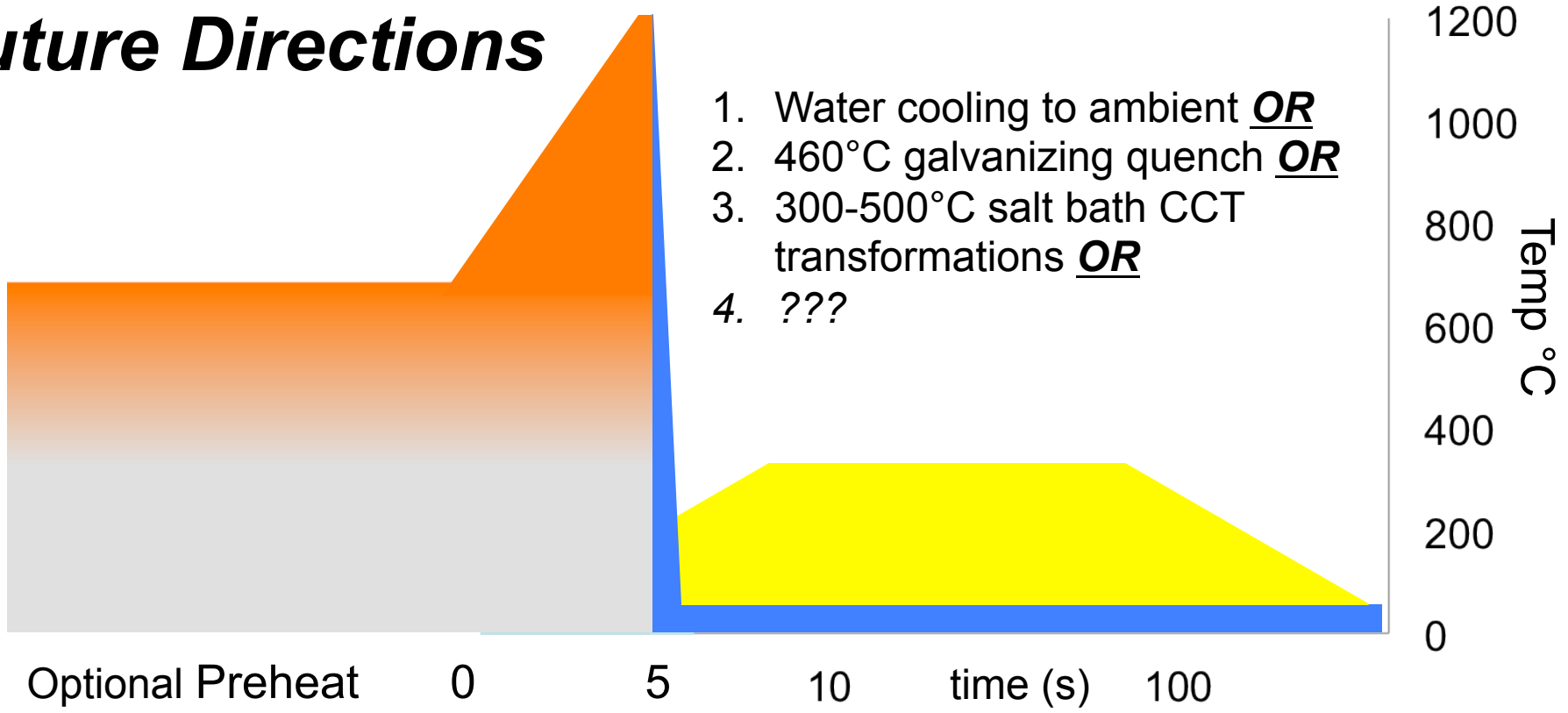
Patented Thermal Cycling



Flash IP claims:

- No pre-heating **OR** lengthy pre-heating to sub austenitic temperatures
- Rapid heating once austenitic temp is reached to above 1000°C
- “Substantially immediately” quenching the steel upon reaching peak temp
- Water spray used to transform to ~20% bainite and ~80% martensite

Future Directions



With ~20% low carbon Bainite transformed by 500°C B_{finish}
~80% carbon/alloy enriched austenite transforms into …

- Nippon Steel owns the patent (USPTO #6,319,338) commonly now known as Q&P by Osamu Kawano et al filed 28Nov1996 in force until 28Nov2017+PTA time.
- Nippon #6,319,338 teaches conventional heating plus holding time above A3, not Flash® heating and immediate quench initiation.
- Atomic interaction of localized chemistry after Flash® heating is a new field of study.
- Prior quench patents are now ***NOVEL*** with Flash® heating as the first method step.

2009 - 2013
Lawrence Tech SAE Baja
Constructed from Flash® 4130





Successfully Completed Endurance Competition

5 Rollovers & Many Boulder Collisions – NO DENTS, NO DAMAGE!!!





Flash® Bainite Weld-Fabbed by College Students. Fifth Vehicle completed …

Conclusions on Flash® Bainite ...

- **Energy efficient method to make ~20% Bainite through carbon lean heterogeneity**
- **High performance Armor for military and civilian uses ~ plates flat within 1.2mm**
- **High performance vehicle structural and crashmember applications**
- **Welds very easily with less severe HAZ due to low carbon content in prior ferrite areas**
- **Temper resistance leads to “warm forming” of stamped parts**
- **With ~20% bainite made above 500°C, how best to quench/transform the remaining ~80% of the austenite?**