Flash® Bainite

Room Temp Stamping 1500 to 1800MPa Structural and Energy Absorbing Components to <2T Bend Radii

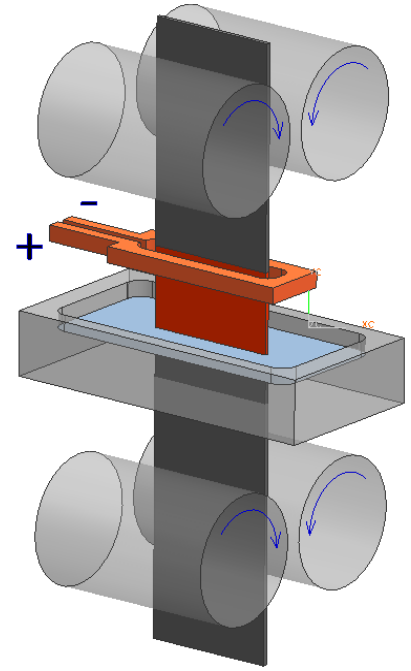
May 7th, 2018

Gary M. Cola, Jr

Acknowledgements:
US Dept of Energy - SBIR Awards:
Phase 1: DE-SC0011850 & DE-SC0011857
Phase 2: DE-SC0011857
Phase 3: ***DE-EE0007877***

Ohio State University &
University of Tennessee - Knoxville
Teams led by Prof Suresh Babu, UTK

Hyundai-Kia America Technical Center, Inc



The Potential

"With widespread use of Flash-processed steels, the US Automotive Industry could save over 100 pounds of vehicle weight per car at a reduced cost."

Dr David Forrest
US Dept of Energy
(5) Grants in (3) years
INDUSTRIAL HEATING, May '17

<10 Seconds to >1600MPa AHSS

Made with "off-the-shelf" Steel & Equipment

… Starts with low cost, easy to produce grades like

AISI1010, 1020, 4130, 1530(PVQ), and 13Chrome SS

… heated in just 2 to 6 seconds

to temperatures over 1832ºF, *often 2100ºF*

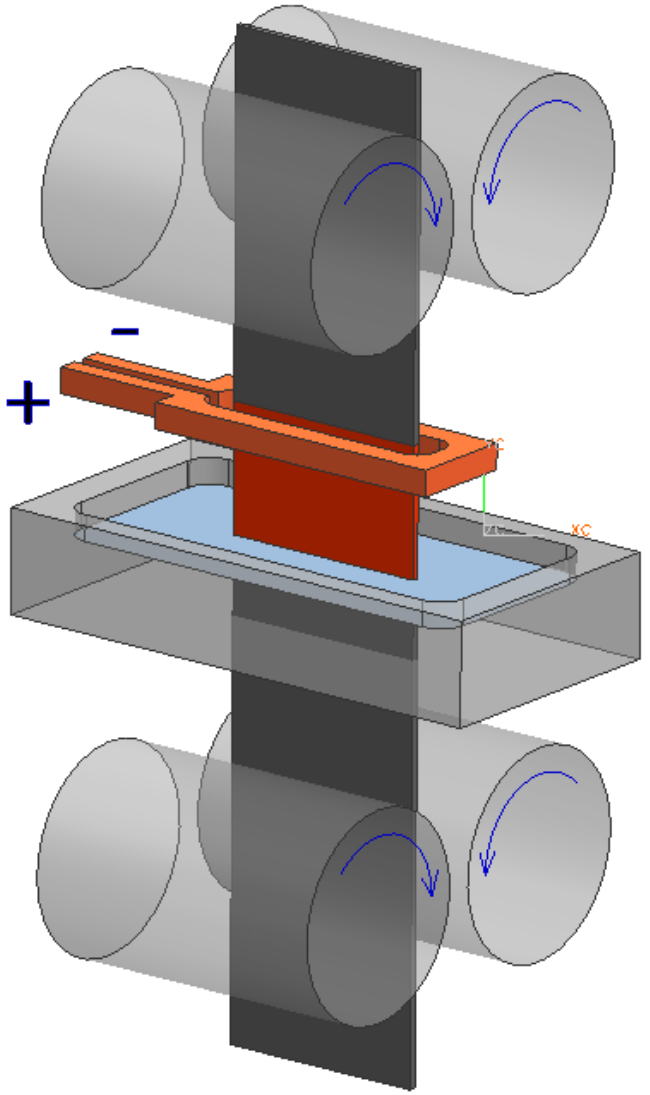
… water quenched just seconds later

… a novel technology controlling heterogeneous

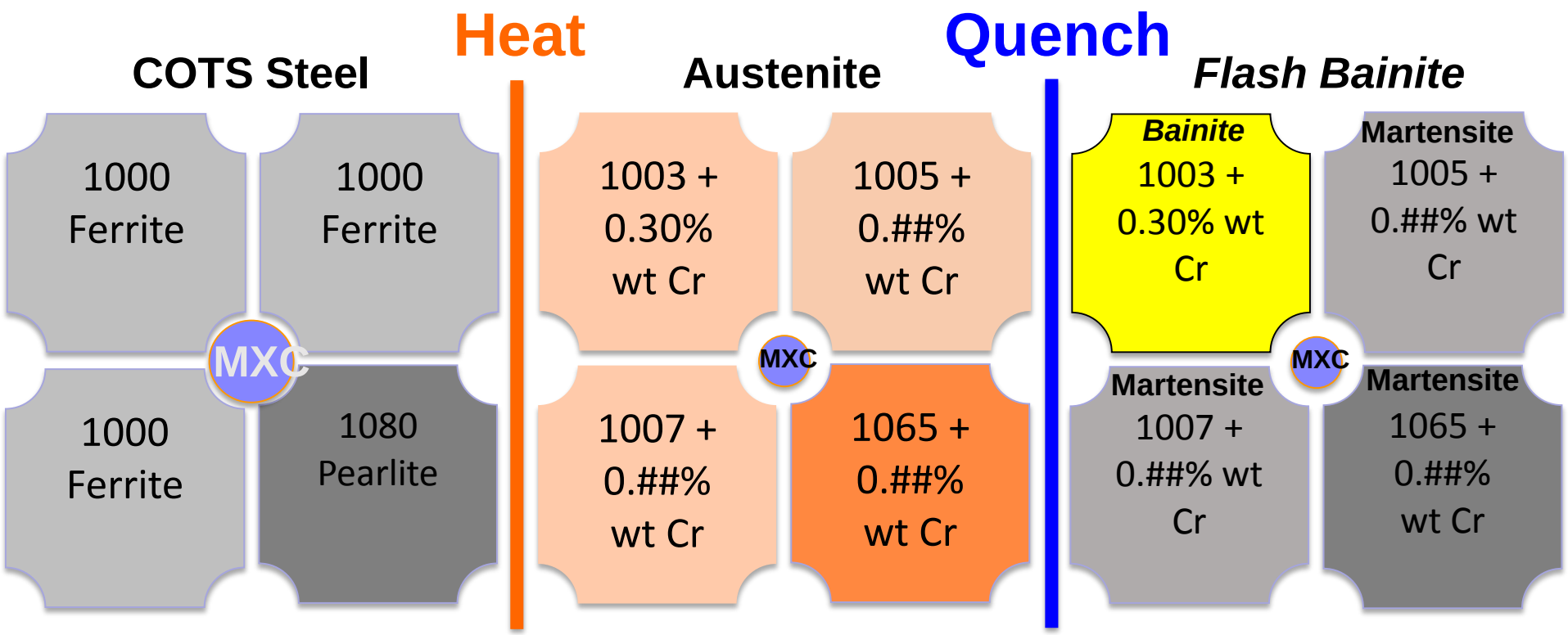
carbon migration and carbide dissolution

for "mixed microstructure" performance

… (12) issued patents around the World, more pending

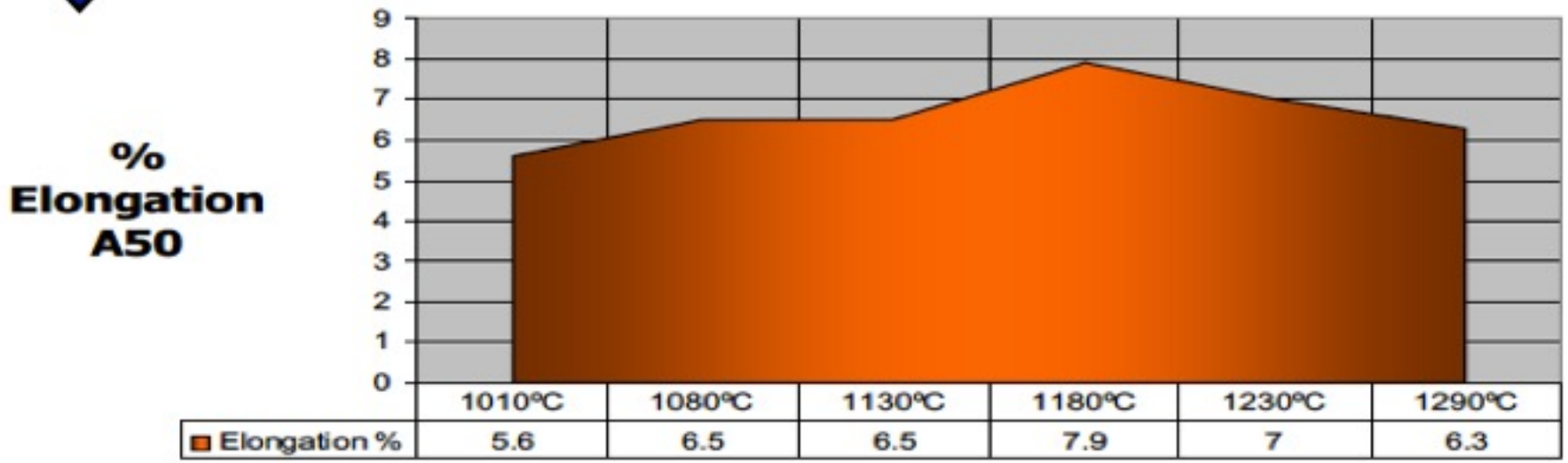


Theory: *Controlling Carbon Migration & Carbide Dissolution*



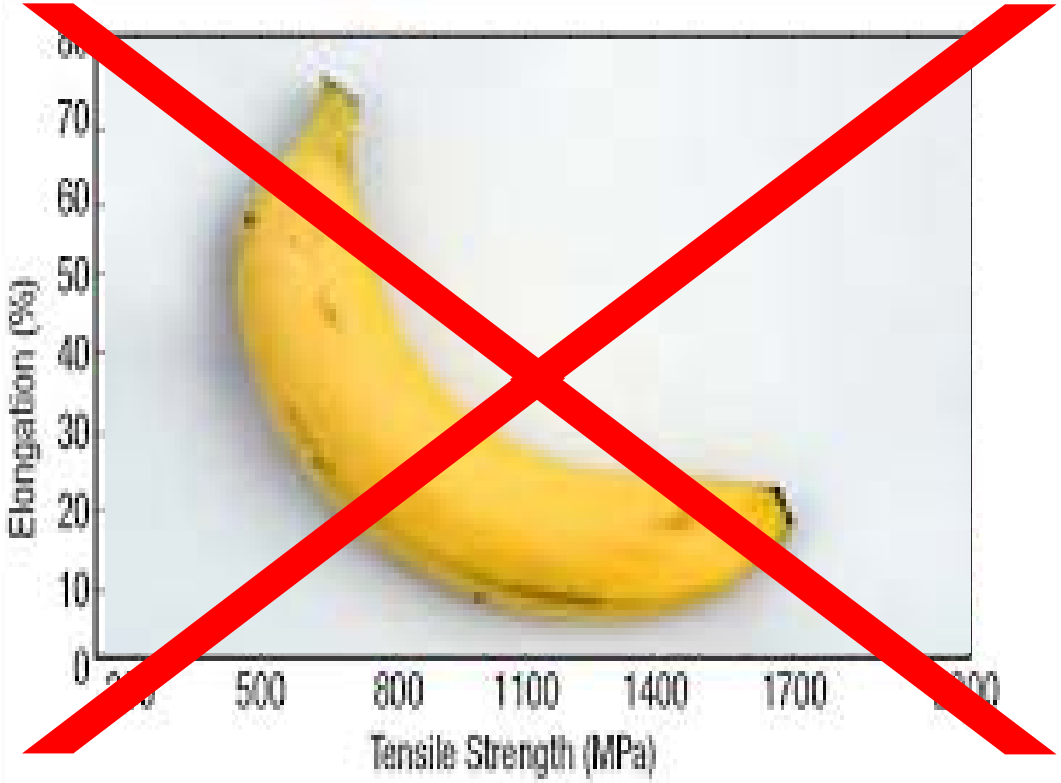
- **Carbon moves rapidly but can be controlled.**
- **Minimal alloying reduces dislocations to limit fracturing.**
- **CCT predicts, TEM/Atom Probe confirm presence of *Bainite.***
- ***Readily weldable*: the vast majority of steel grains are very lean.**

Peak Heating Temperature Analysis of AISI1010 at 0.10%wt C



- 1080°C to 1290°C produced a 900MPa yield and 1100MPa tensile strengths.
- A peak temp of 1180°C provided the most total elongation.
- A peak temp of 1010°C resulted in only 720MPa yield and 900MPa tensile strengths at lower elongation.
- *A preferred peak heating temp for larger PAG sizes appears to lead to increased strength and highest elongation provided that an upper limit is not exceeded . . . but why?*

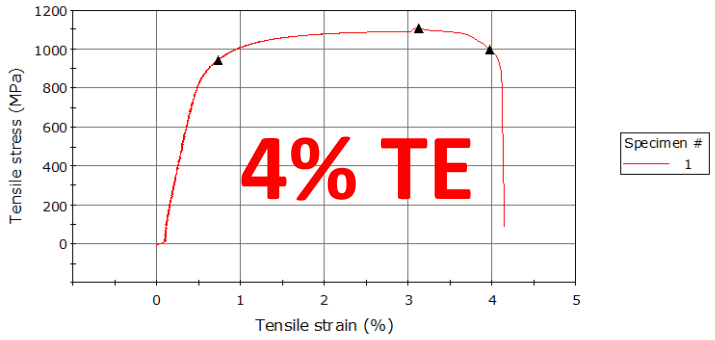
More Important Than “Elongation” and “Banana Curves” . . .

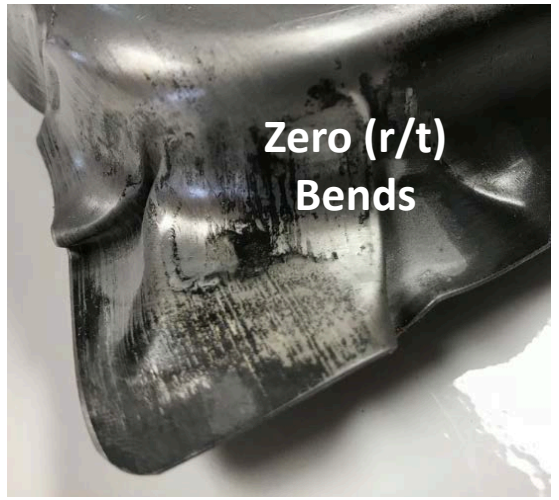


TM E8 SHEET TYPE, ASTM E18, ASTM A90

	Width (mm)	Thickness (mm)	.2% Offset Yield (MPa)	YPE (%)	Tensile Strength (MPa)	Elongation (%)	Uniform Elongation (%)	n-Value (YLD - UE) ()	K-Value (YLD - UE) (MPa)	r- Value @ UE ()	rm ()	Spec n La
1	12.78	0.56	942.4	-----	1108.8	4.0	3.1	0.108	1669.1	0.306	0.000	3
ean	12.78	0.56	942.4	-----	1108.8	4.0	3.1	0.108	1669.1	0.306	0.000	
andard viation	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	

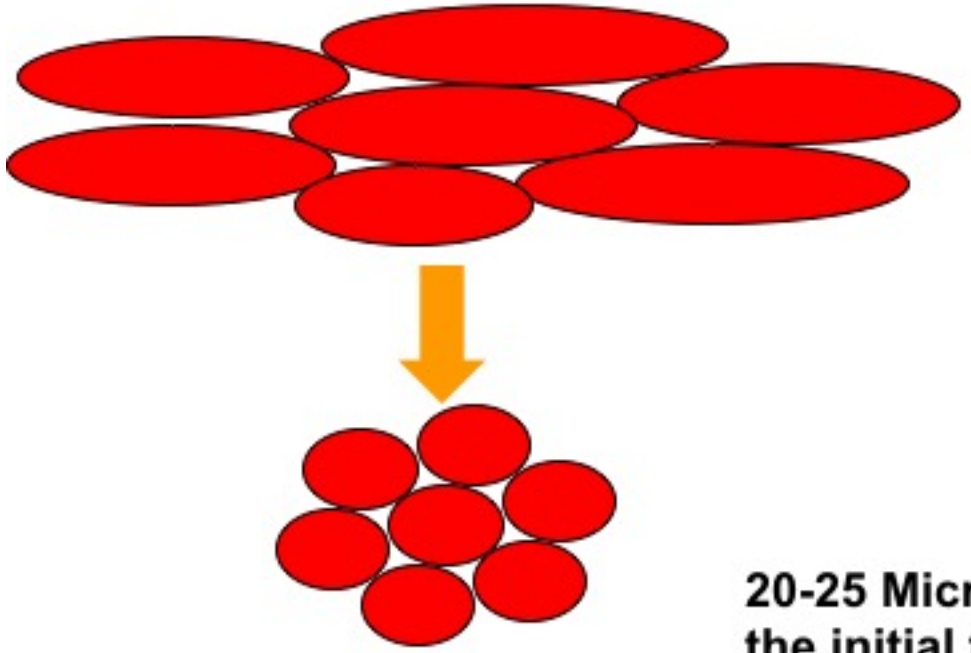
Specimen 1 to 1



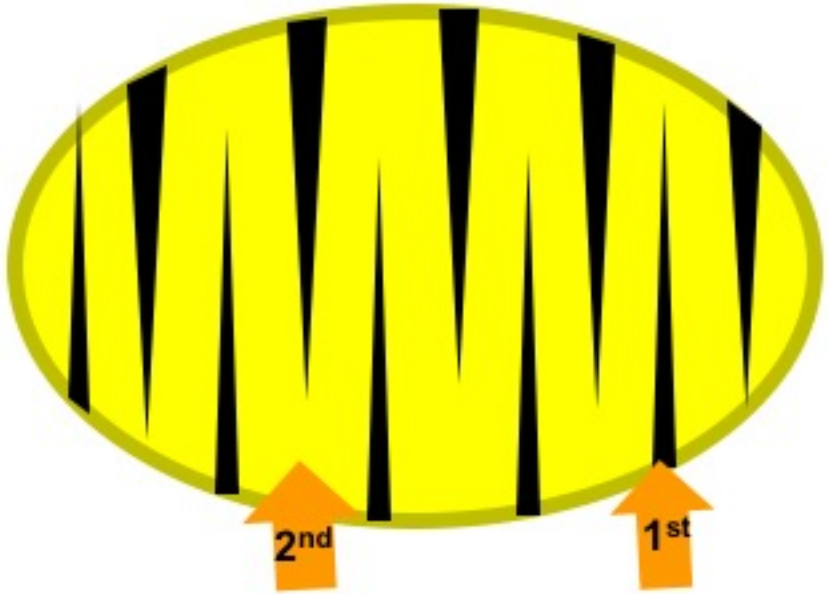


- “Banana curves” of uni-axial elongation do not tell the entire story.
- Bending is more important in forming many structural components.
- Too high of elongation can lead to thinning in critical structural regions.

Novel Grain Refinement for Higher Strength Formable Steel



2-4 Micron Grain Size Achieved w/ Conventional Processes



20-25 Micron PAG sizes can be internally refined by the initial formation of acicular daughter phases, including bainite (shown black), that form above the Ms. Untransformed austenite (yellow) can then form nano-scale martensite upon further cooling.

- This mechanism is currently under review at ORNL and UTK under grant from US DOE.
- Note that 2-4 micron grain sizes have a significantly higher "surface area to volume" ratio than 20-25 micron grain sizes. An order of magnitude less surface area is common
- Does less grain boundary surface area lead to less potential hydrogen embrittlement?

Simplified Equipment

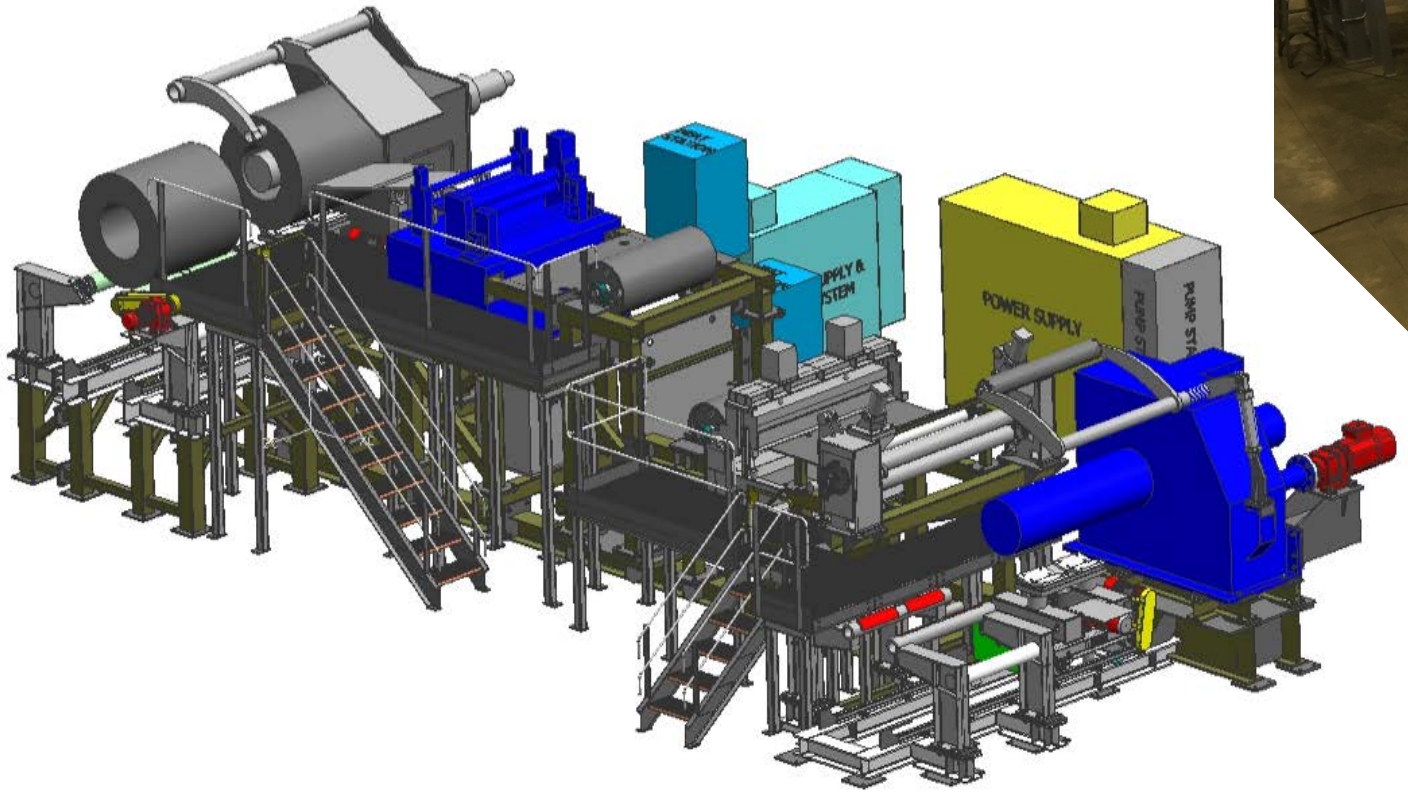
Lower CAPEX, Retrofit into Existing Mills,
Significantly Less Floorspace,
Higher Margins

Flash® Armor Plate Line

Transforming AISI41## into the World's Leading Armor In Just Minutes

With Roots in Defense, *Armor Technology for the Auto Industry*

$1.3MM Flash® Bainite SBIR Phase III Production Line

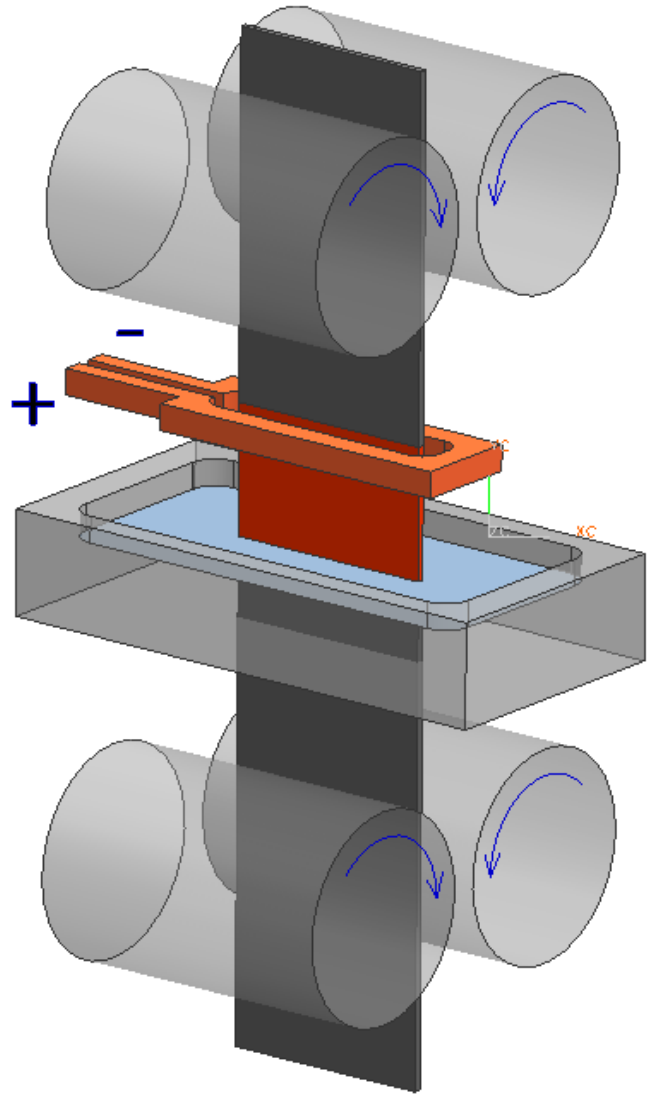


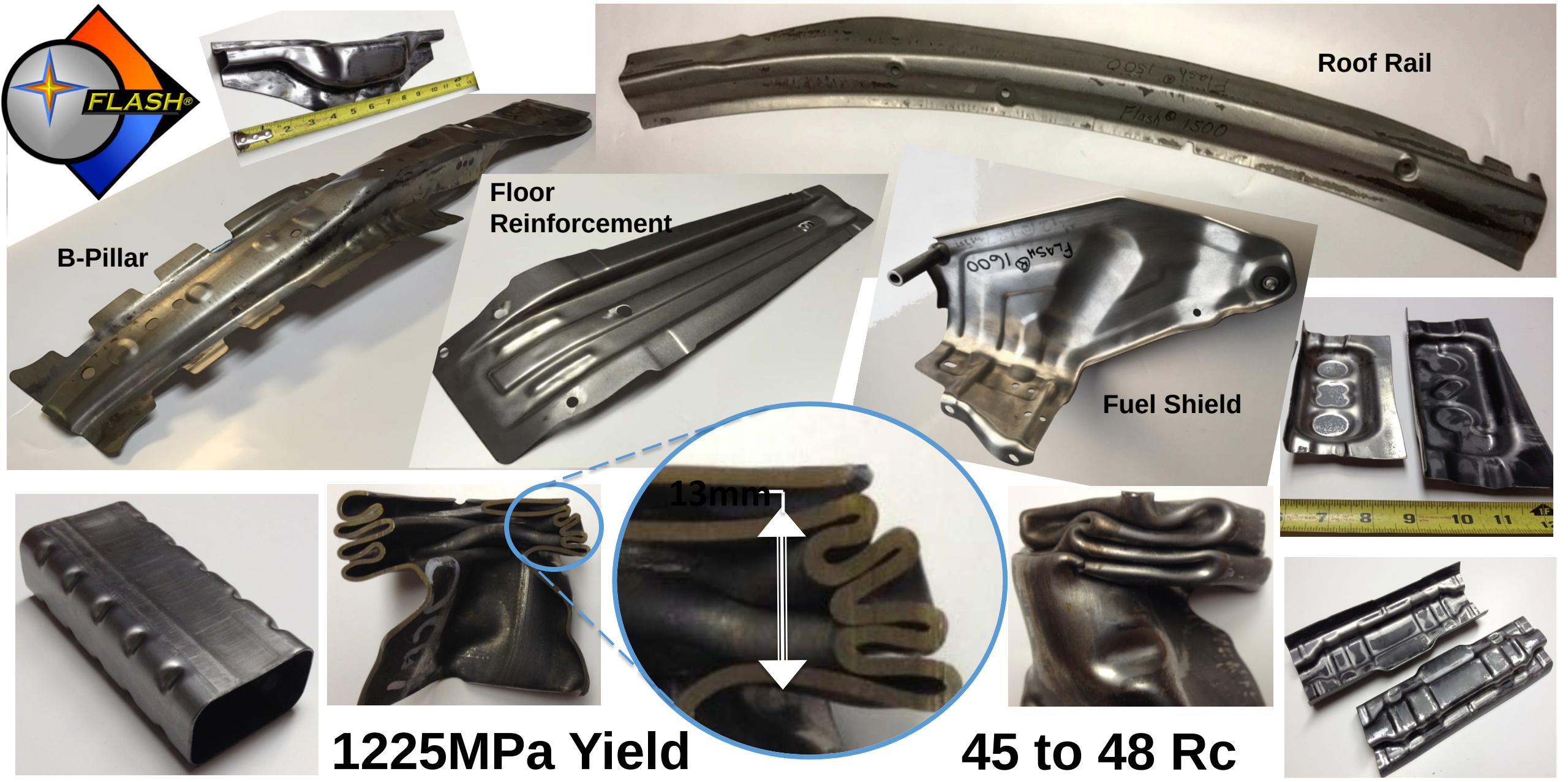
Mechanically Complete
Electrification Underway
Full Operation Q3-2018

Funded by the US Dept of Energy,
built by SES, Fluxtrol, and Ajax TOCCO

Practical Applications

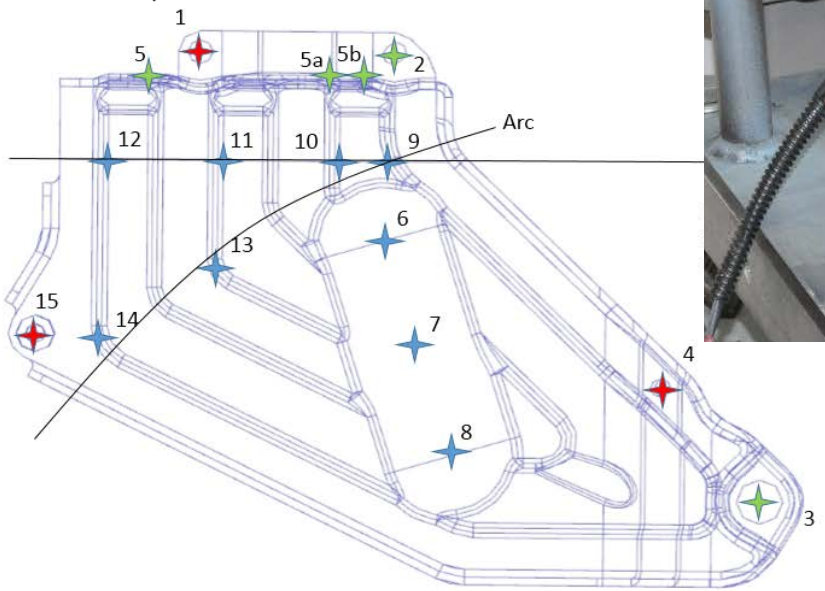
Meeting the Auto Industry's Needs

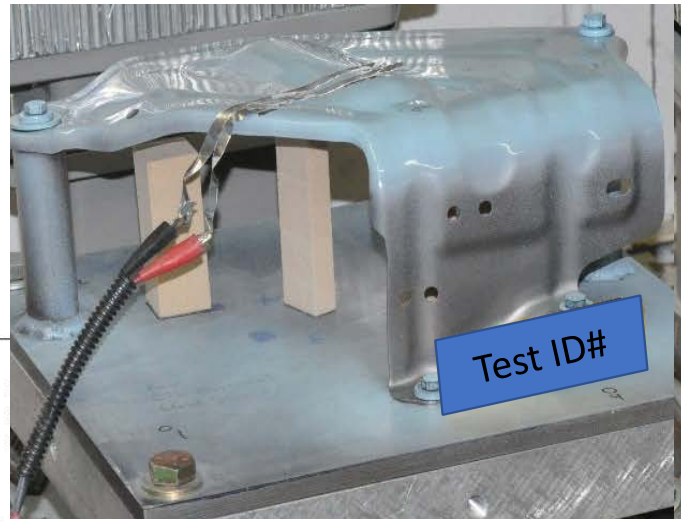


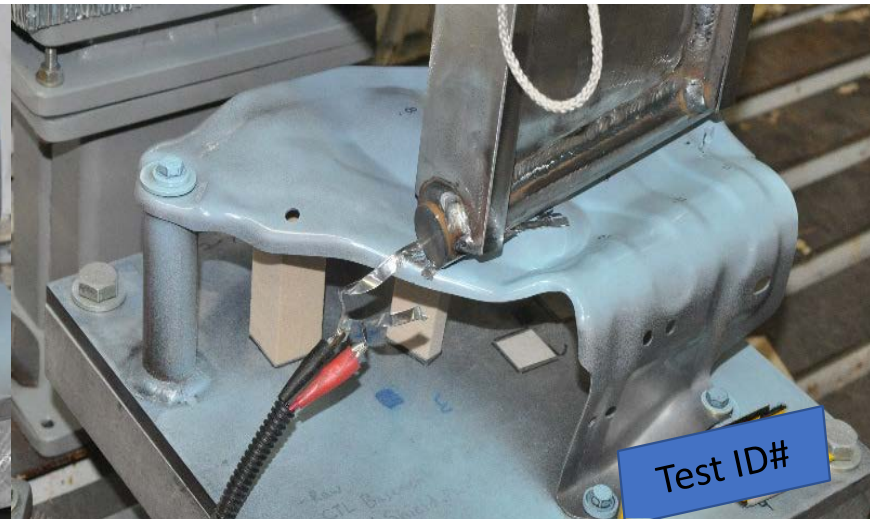


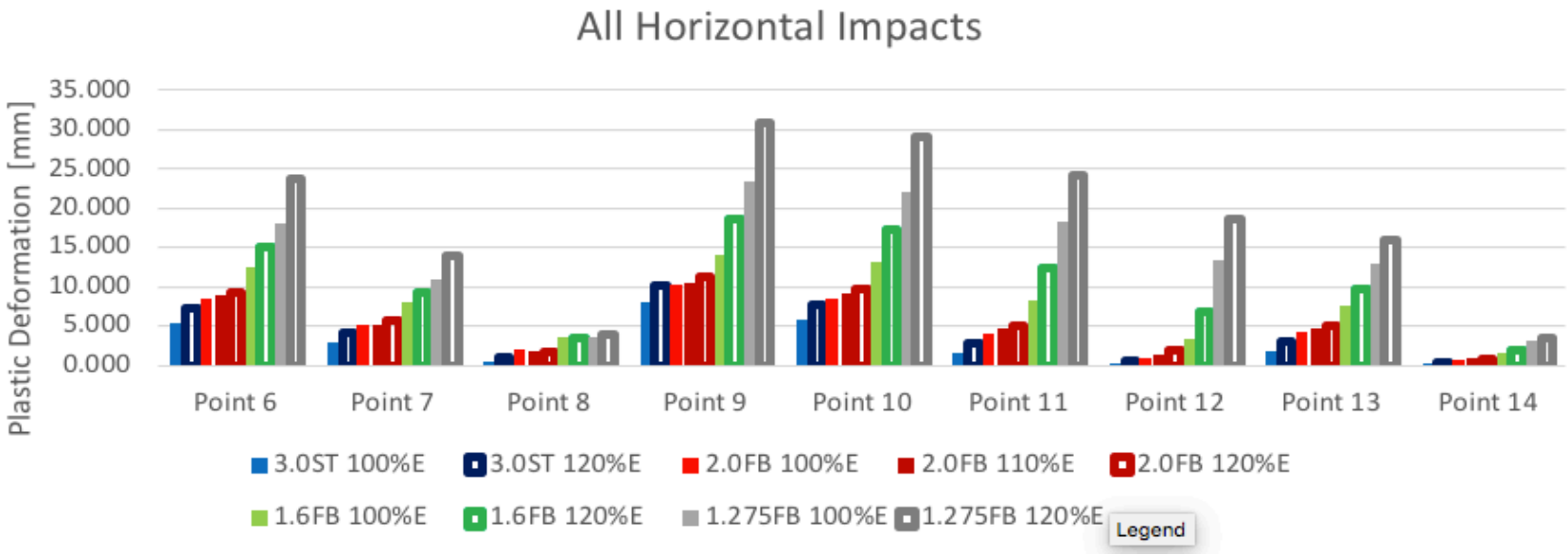
***AISI1020* leads to >20 Cold Stamped Parts up to 57% Mass Savings**

OEM Fuel Barrier Testing



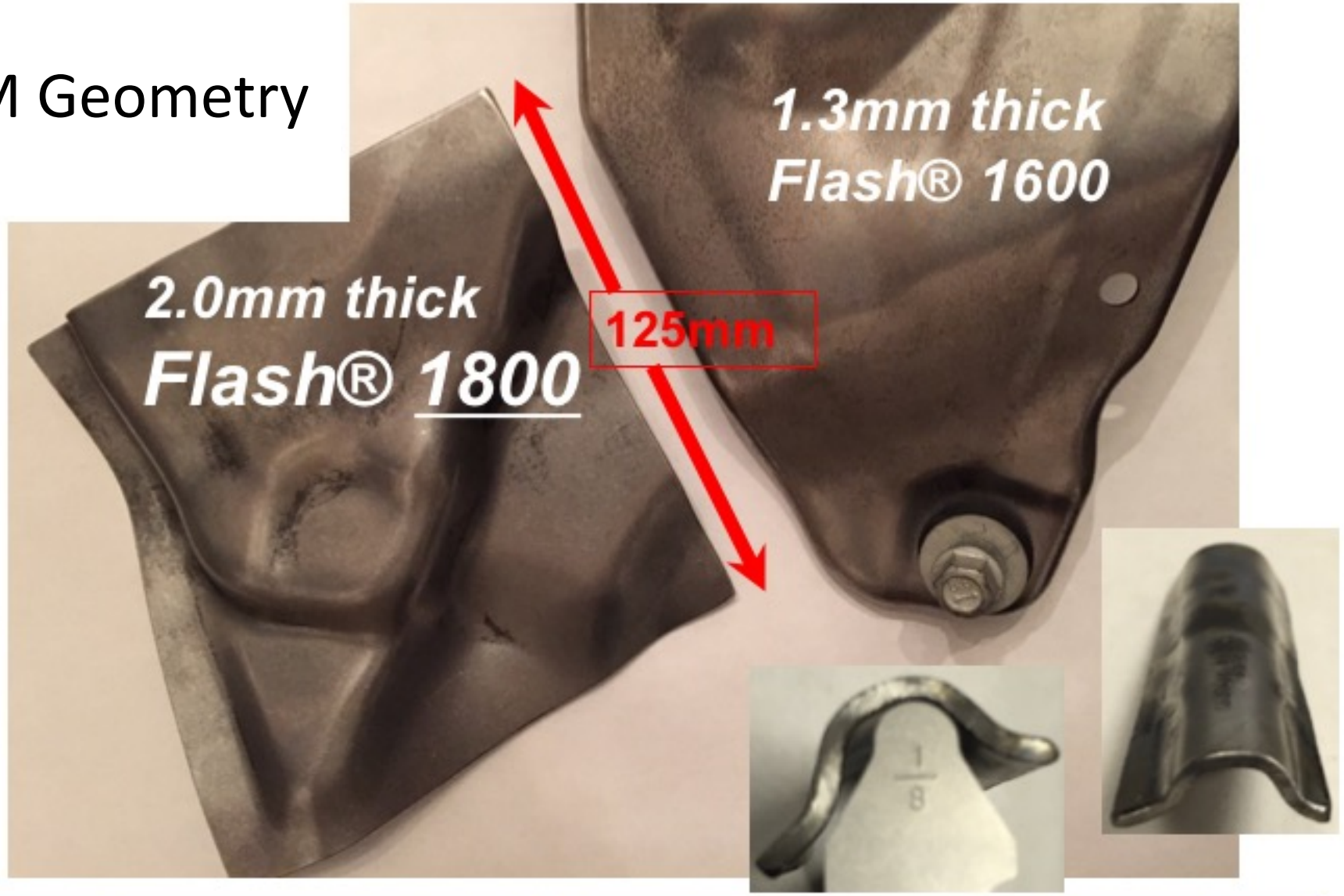






2mm Flash 1500 Performs like 3mm Shield, but 1lb (33%) Lighter

OEM Geometry



- Cold Stamp-able *Flash® 1800* averages 1420MPa yield, 1800MPa UTS, and 8.4% A50 total elongation
- Flash® 1800 displays "bend-ability" to 1.5T

Flash® SS - 3rd Gen AHSS Sheet

1800MPa at 12% Elongation

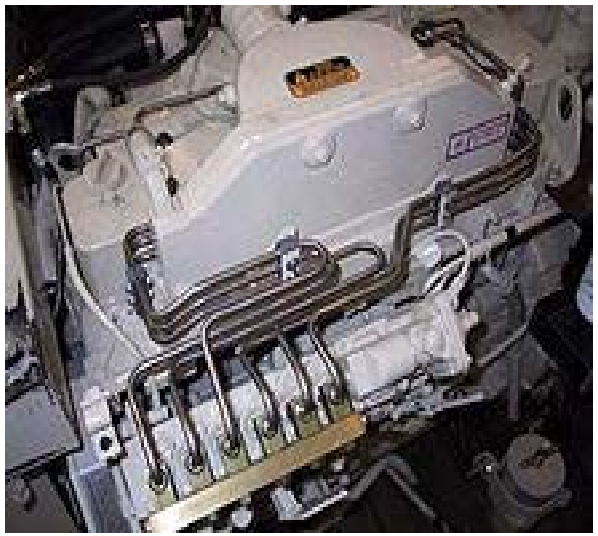
Flash SS, made from 13Chrome stainless steel.

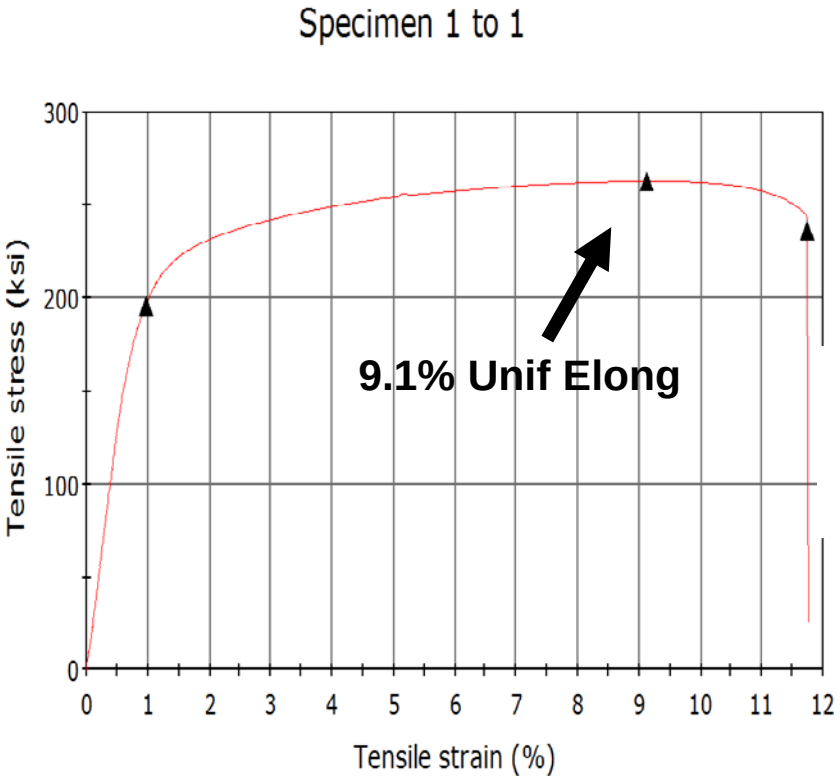
Beyond Automotive, uses in Oil & Gas, Cutlery, Food Storage, and much more.

Per mass: **2X the strength of 6061-T6 aluminum**
Equaling the very best Ti-64 STA Bar

Proven bends to 2.5(r/t)

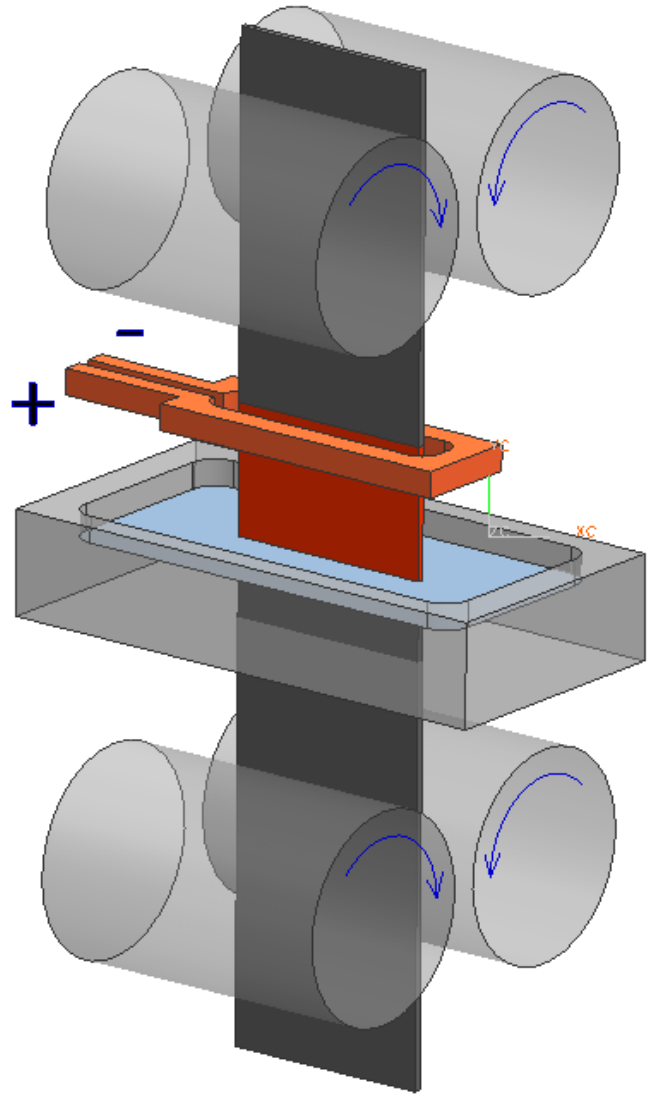
	Width (in)	Thickness (in)	.2% Offset Yield (ksi)	YPE (%)	Tensile Strength (ksi)	Uniform Elongation (%)	Elongation (%)	Total Elongation (%)
1	0.500	0.062	196.2	-----	262.7	9.1	11.7	11.7





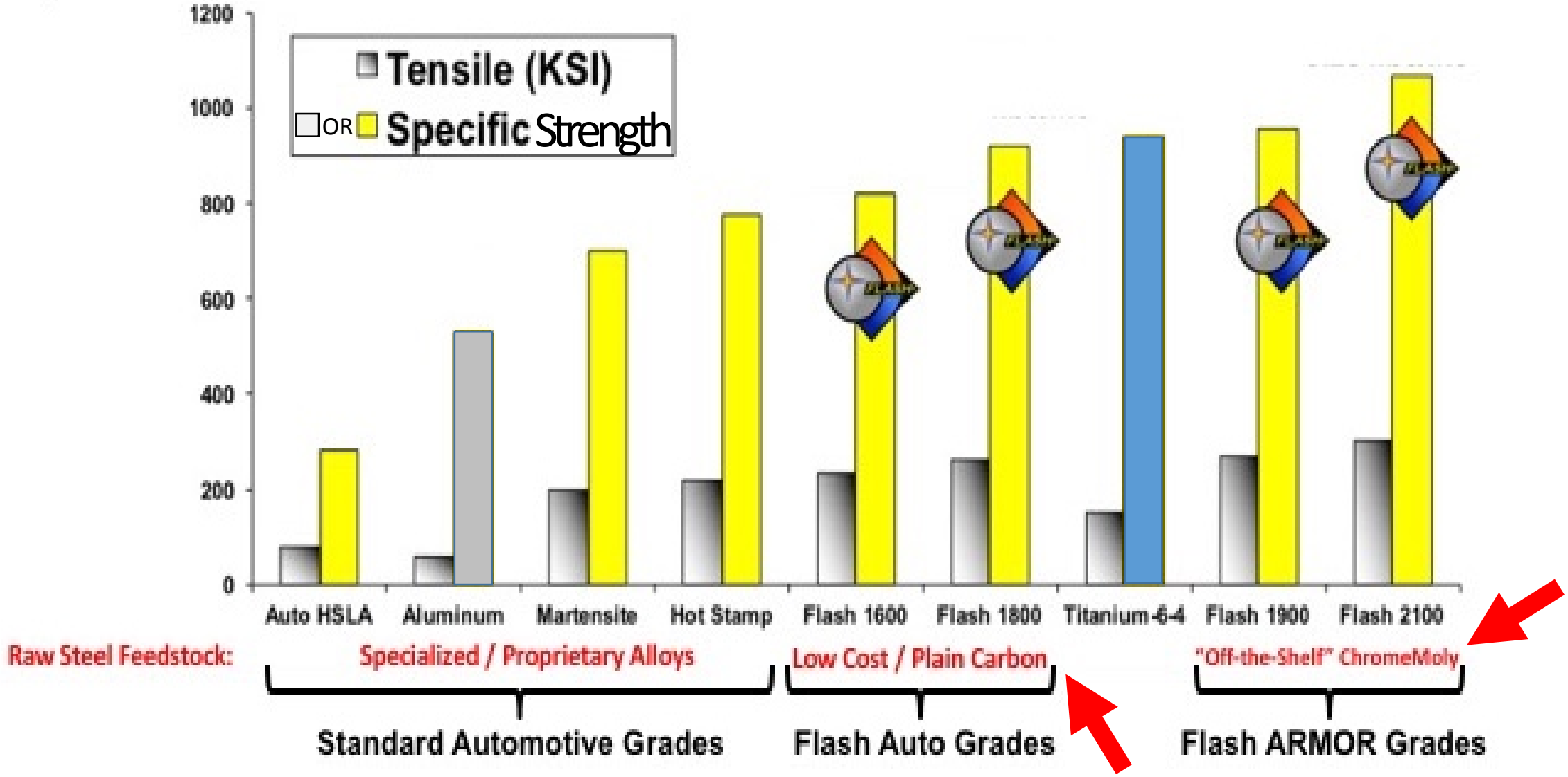
Performance

Competing for Market Share in a Lightweight World



Flash®: In the $2T Metals Industry . . .

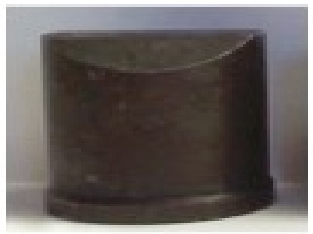
Stronger Metal for Lighter Parts



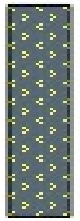
Flash® Needs Less Mass to STOP the Same Bullets or Blast

Armor Piercing
0.30-cal Bullets

Required to Stop



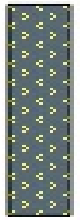
Standard 20mm
Blast Fragments

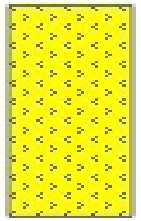


10psf

1/4"
Flash® 500

10psf

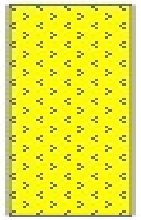


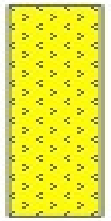


12psf

~ 1/2"
Titanium

11psf

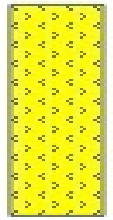


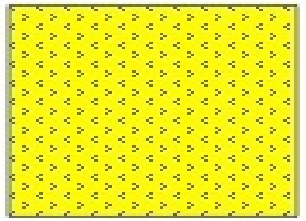


16psf

~ 3/8"
High Hard

>16psf?

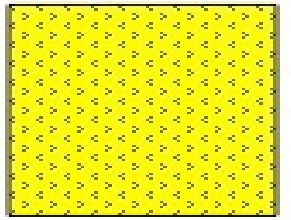




17psf

~ 1-1/8"
Aluminum

16psf



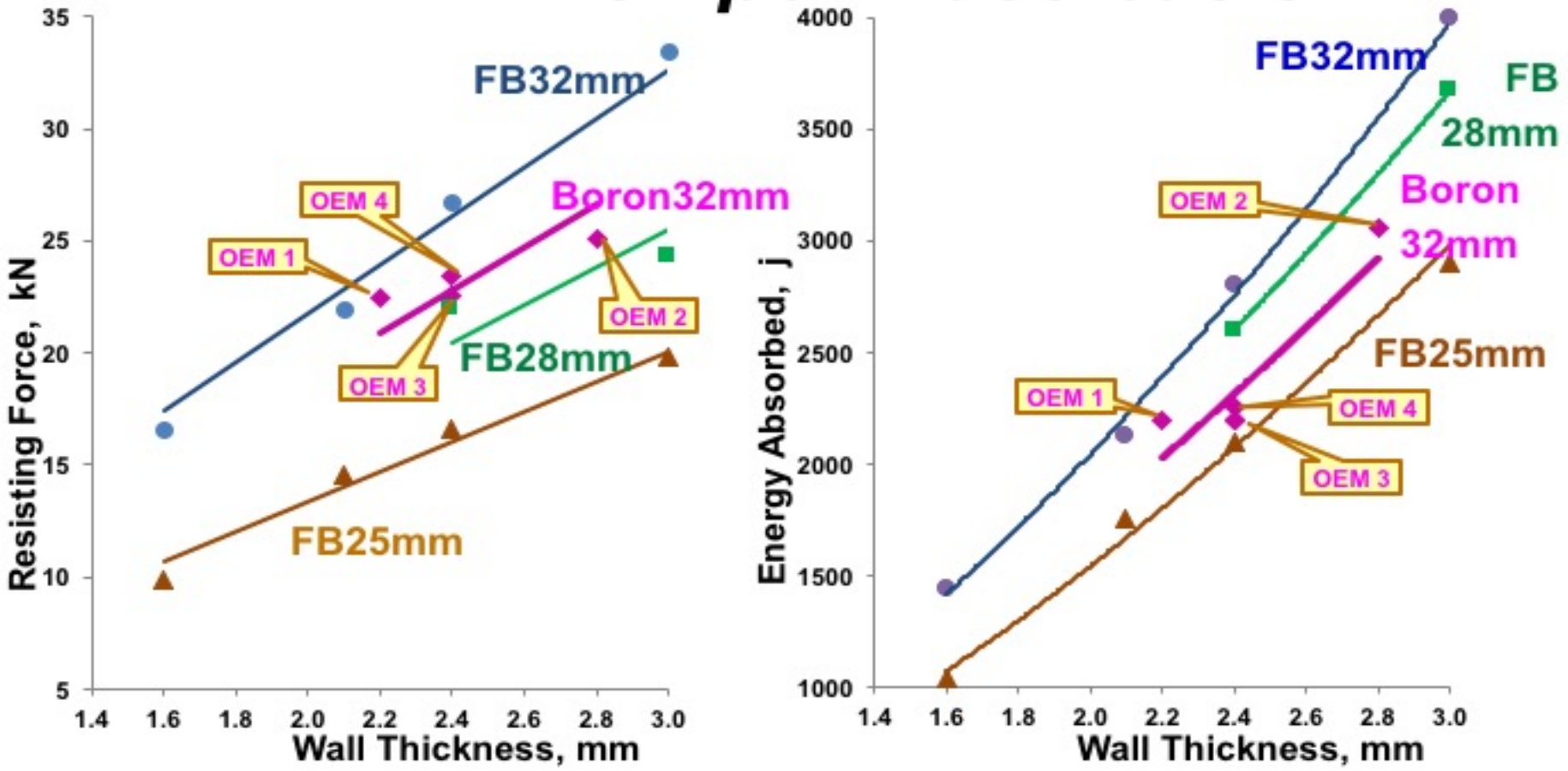
psf = areal density in pounds per square foot
As tested by US Army Aberdeen Test Center

After 6 months of intense testing, the US Army wrote:

"The novel Flash Bainite process for steels has the potential to reduce cost and weight while also enhancing mechanical performance."

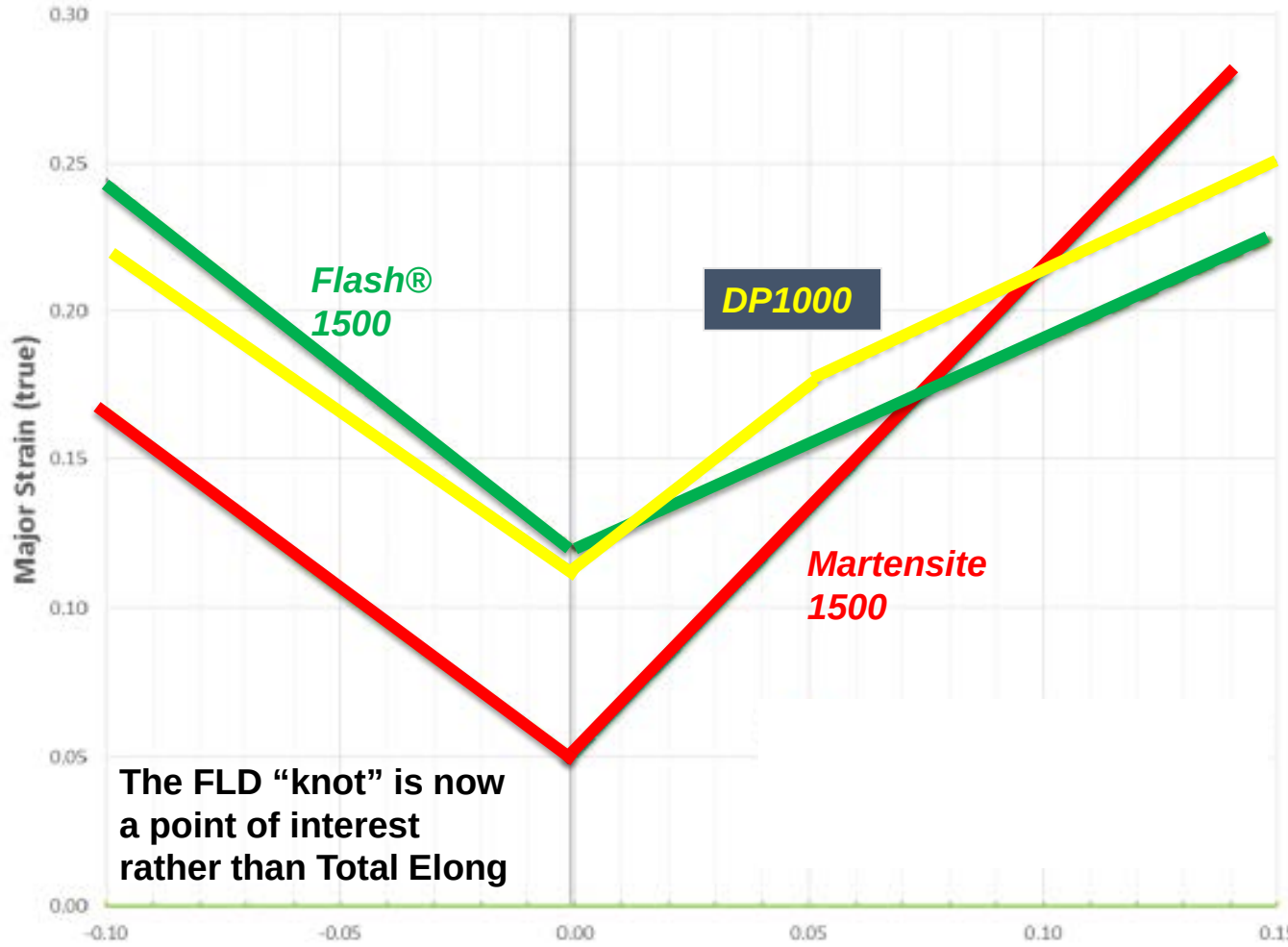
Flash vs Boron Tubing …

on per mass basis



- ***At the same geometry and mass, Flash Tubing has ~15% higher Resisting Force and ~20% more Energy Absorbed than Boron Tubing.***
- ***Increased Carbon But Still Very Bendable and Weldable, not Brittle***

Forming Limit Curves: *Flash® 1500, Martensite 1500, DP1000*



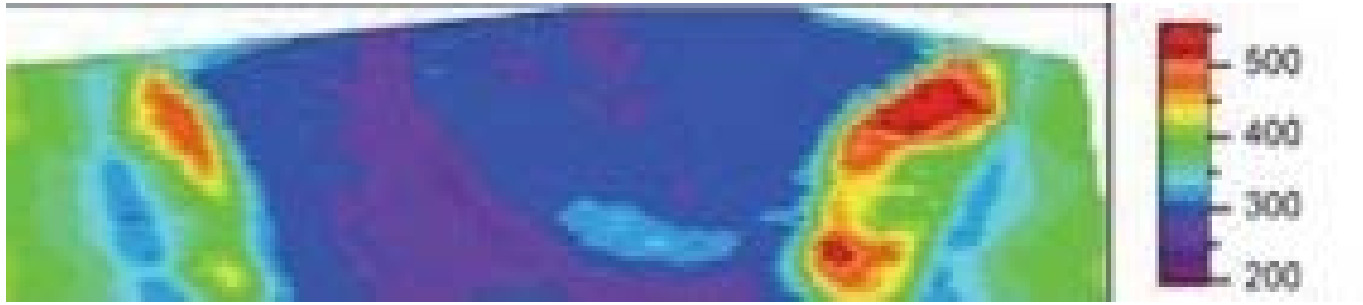
Mechanical Properties

Flash® 1500
Thickness: 1.3mm
Yield: 1200MPa
Tensile: 1500MPa
Ratio: 80%
Elongation: 6.8%
Minima Pt: 0.12

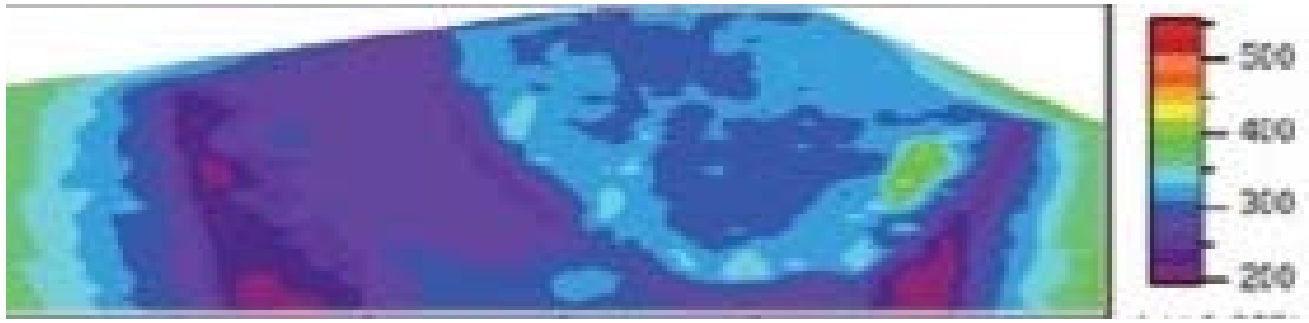
Martensite 1500:
Thickness: 1.4mm
Yield: 1400MPa
Tensile: 1550MPa
Ratio: 90%
Elongation: 6.1%
Minima Pt: 0.05

- **"Total Elongation" is similar to M1500, yet the novel Flash® 1500 microstructure offers notably higher "form-ability" and is able to bend to 0T/1T radii, thus reinforcing the notion that "total elongation" is disconnected from "bend-ability".**
- **FLD's show the novel Flash® 1500 microstructure matches the "form-ability" of DP1000 (which is only 2/3 as strong yet has double the elongation).**

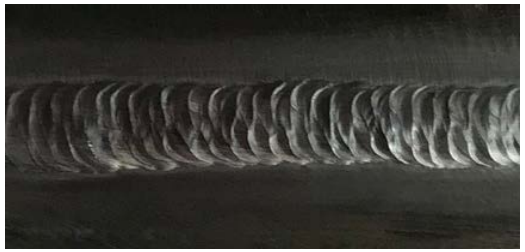
Flash® Bainite: Non-Brittle Welds

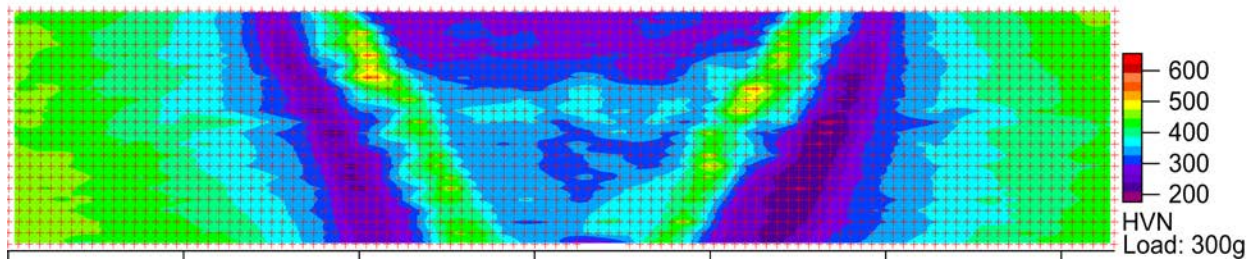


High Hard 500



Flash High Hard 500

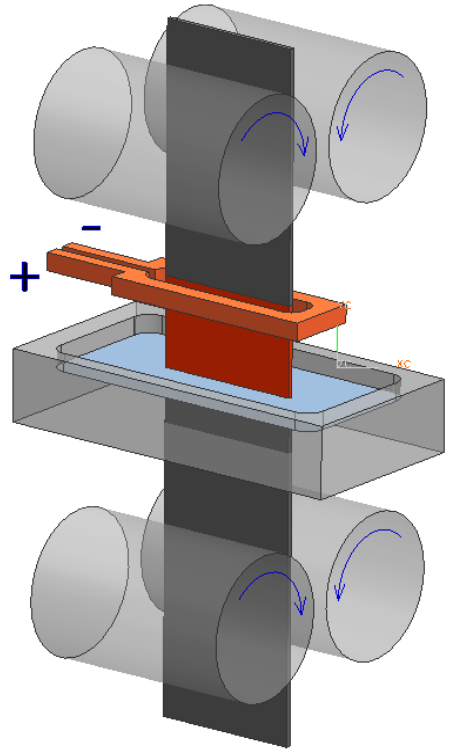




Flash Ultra Hard 600

Hardness Mapping of 1/4” Thick Weld Seams of Armor Plate using mild steel rod at room temp:

- **Typical High Hard 500 (Brinell), Flash High Hard 500 Plate, and Flash Ultra Hard 600 Plate**
- **RED regions show fresh embrittlement**
- **Hardness Mapping by ORNL-Univ of Tennessee Knoxville**



Sustainability

Plain Carbon Steel + Minimal CAPEX & Energy = ***High Performance & Profit***

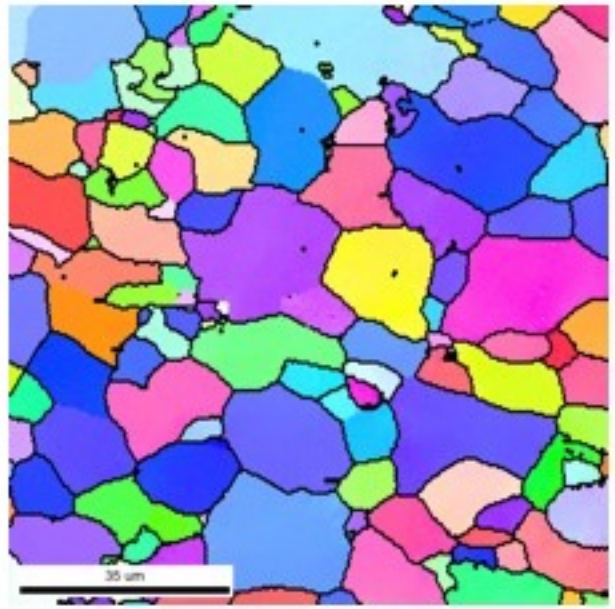
Stronger, Highly Bendable, Energy Absorbing Steel = ***Safer Cars***

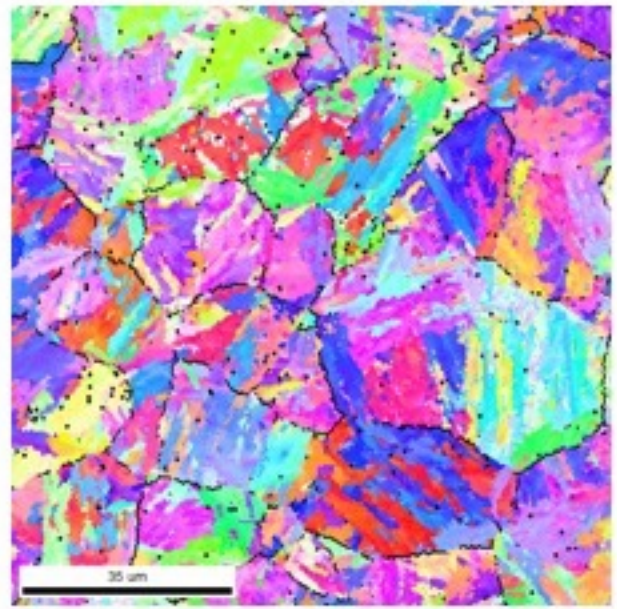
Lighter Cars = ***Higher Fuel Efficiency***

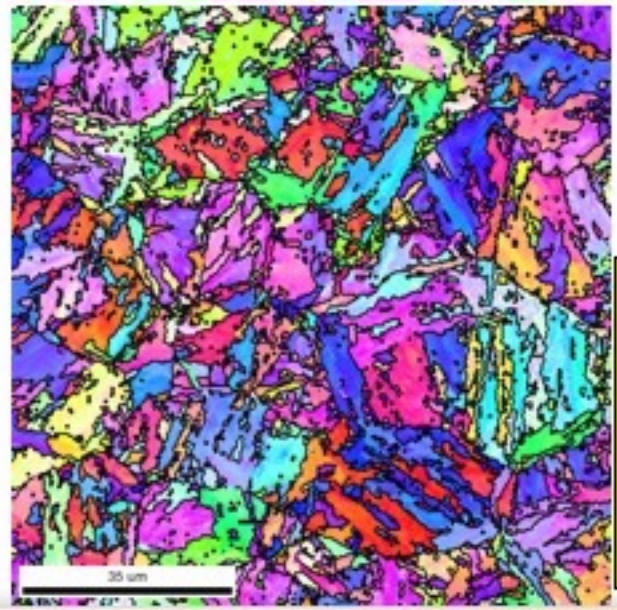
Flash is Just the Next Step in the Life-Cycle of Steel,

The Most Recycled Product on Earth

Flash® Processed AISI1020 Analysis







	#6S .23
Ferrite	11.4
PAG	22.4
Block	3.6

9 Heats of Steel
5 Different Steel Mills
Carbon: 0.18-0.23wt%
Cold and Hot rolled
Sheet and tube
Thin and thick wall

All (9) EBSD Results Indistinguishable from each other After Flashing

Thank You!!!

Practicality – Flash® Automotive to Shipping to I-Beams and Rebar

Performance – First a record setting Armor technology, and now even Stainless, **"Flashed AISI1020" offers 20-50% mass savings**

Marketability – Flash® created the field of "ultrafast AHSS" cold stampable sheet **reducing mass and cost in better components**

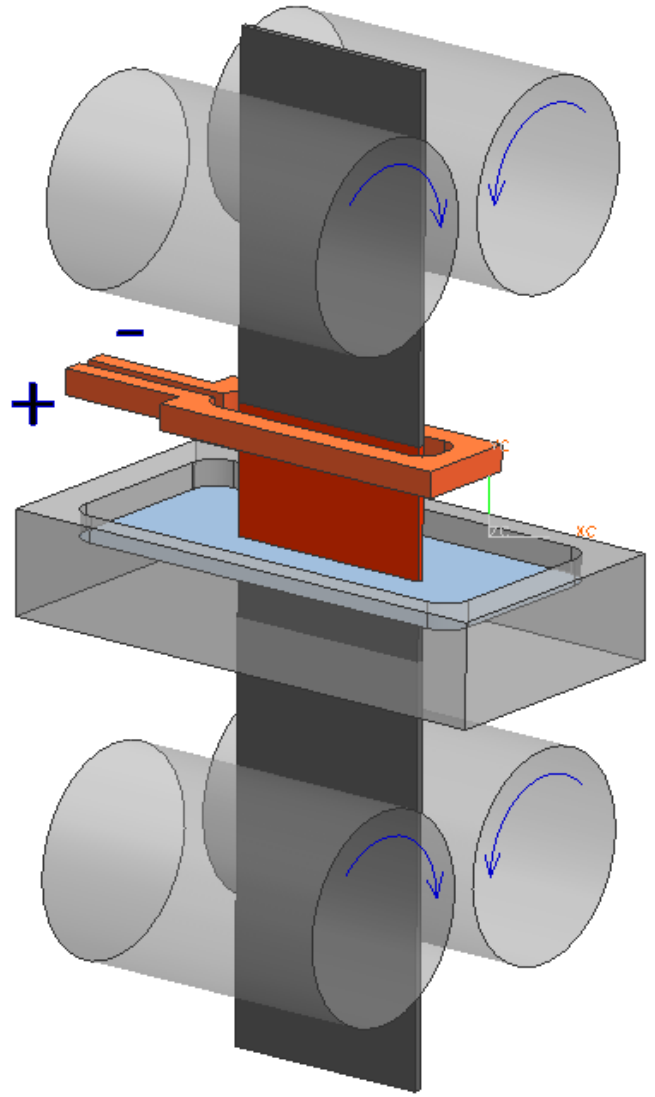
Sustainability – Offers increased safety, fuel efficiency, lower Steel Mill emissions, widespread Industry opportunity, and **40% profit margins**

Demand – Flash is exactly what $Bs in AHSS Research has sought for decades

All With the Familiarity of Steel.

FLASH BAINITE
MAXIMUM STRENGTH STEEL

Backup Slides



General Motors Led a (3) OEM, (4) Steel Mill Team On 1500MPa Development for AHSS

After Four Years and ~$10MM:

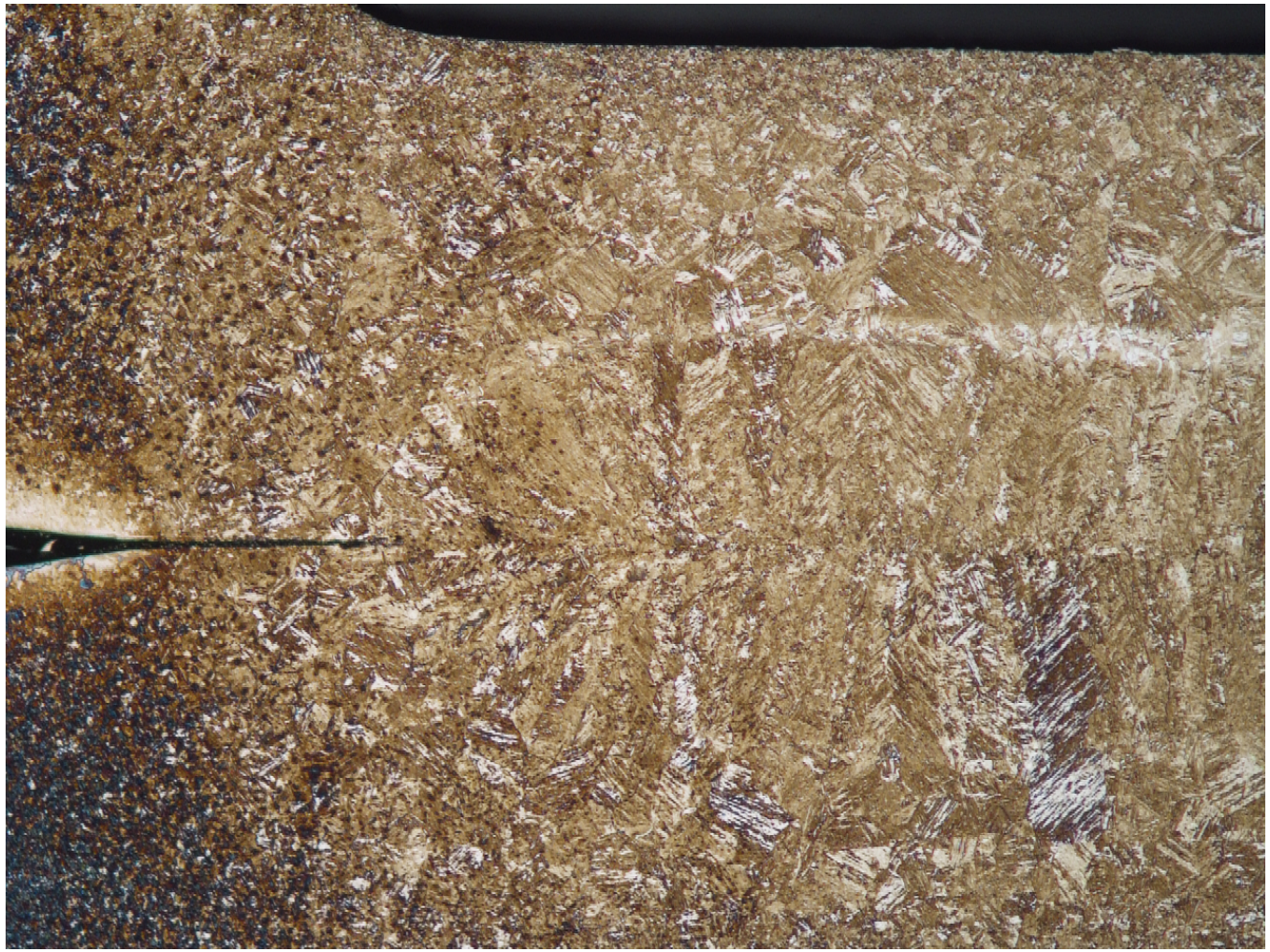
***Elevated Manganese Research Grades* of AHSS that contain Retained Austenite Have Brittle Spot Welds**

GM wrote on May 31st, 2017:

- *"It is becoming increasingly clear that* C Red 50X-2
  a re-evaluation of general chemistry / processing strategies is needed
  for current and future retained austenite bearing steel designs"
- *"most challenges are currently considered as manageable with the exception of the presence of* ***liquid metal embrittlement of resistance spot weld(s)"***

LME in 1500MPa Gen-3 AHSS seems like it is going to be a Bigger Problem than at 1180MPa. WHAT'S NEXT?

Galvanized Flash® 1600 (MPa) Spot Weld Investigation



Liquid Metal Embrittlement is NOT readily found

Likely due to <1%wt Mn and lack of retained austenite, more review underway

Flash® Bainite: *1500 to 2100MPa Proven VS the Gen 3 AHSS Research Grades*

	DP1180	NXG1200	Q&P 1500	Med Mn 1500	Flash 1500-2100
Production Status	Production	Development / Production	Research Project	Research Project	Development /Production
Alloy Content (wt%)	4	5 – 8 ???	6-8	10-15	2-3
Cost Reducing ($/lb)	$0.75	Est $1.25-2.00 "near stainless"	Costly due to alloy content	Costly due to alloy content	$0.60+profit but less #s needed
Weldability	Yes	Yes, but some brittle "LME"	**NOT WHEN GALVANIZED**	**NOT WHEN GALVANIZED**	Yes, no evidence of LME found
Manufacturability	Coils made	Coils made	Unknown at alloy content	Unknown at alloy content	Uses "off the shelf" steel
Shapes Possible	Sheet, Welded Tube	Sheet, Plate Welded Tube	Too early to predict	Too early to predict	Sheet,Plate,Tube, ***LONG PRODUCTS***
Yield / Tensile Ratio	60-70%	<50%	50%	50%	75-80%
Markets	Automotive & Sheet metal	Y/T Ratio and Exclusivity	Too early to predict	Too early to predict	Auto, Armor, Bridges, Rail, etc

Why can Flash® Bainite form parts this Strong?

Heterogeneous complexity can lead to ~

"Maximum Strength™" in Steel

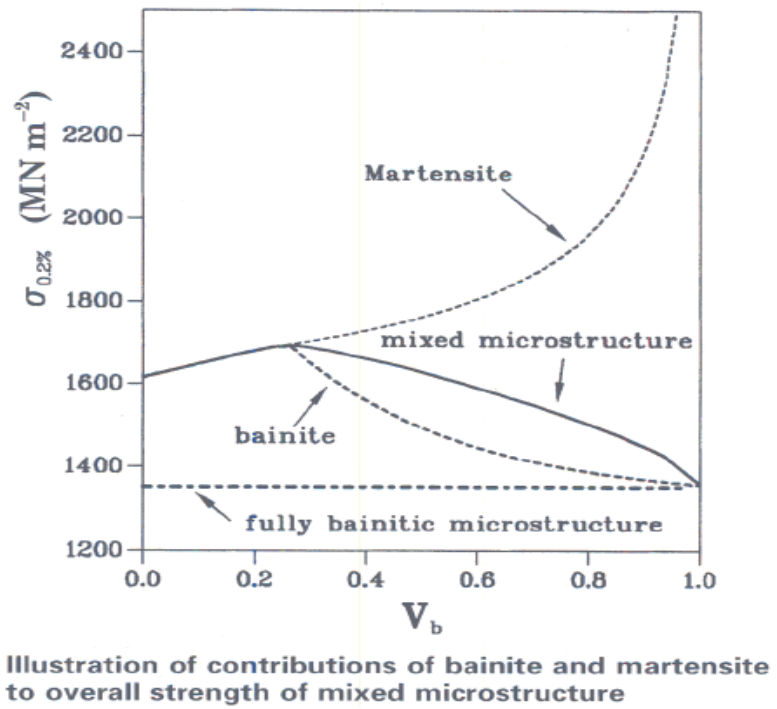
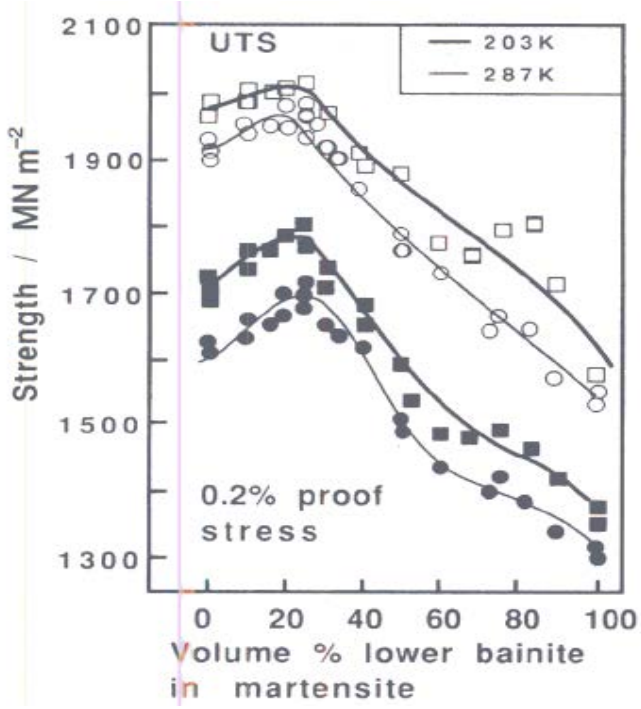


Illustration of contributions of bainite and martensite to overall strength of mixed microstructure



Research by: **Tomita and Okabayashi** **Young and Bhadeshia**

It has been known for 30 years that ~25% Bainite and ~75% Martensite is stronger than ~100% Martensite

Weight Reduction & Cost Savings

- **Stamping of numerous OEM parts shows Flash® 1600 forms as well as DP1180**
- **Parts made of DP1180 weighing 12 lbs (1.6mm) could be Flash® 1600 at only 9 lbs (1.2mm)**

Material	Raw Mat'l Cost / Lb	"All in" Cost to Flash® / Lb	Part Weight	Total Mat'l Cost
DP1180	$0.75	------	12	$9.00
Flash® 1600	$0.45	<$0.15	9	$5.40

25% Less Mass at a Potential 40% Cost Savings - Significant Margin Possible

Auto OEMs Will Pay For Billions of Dollars in CAFÉ Penalty Avoidance