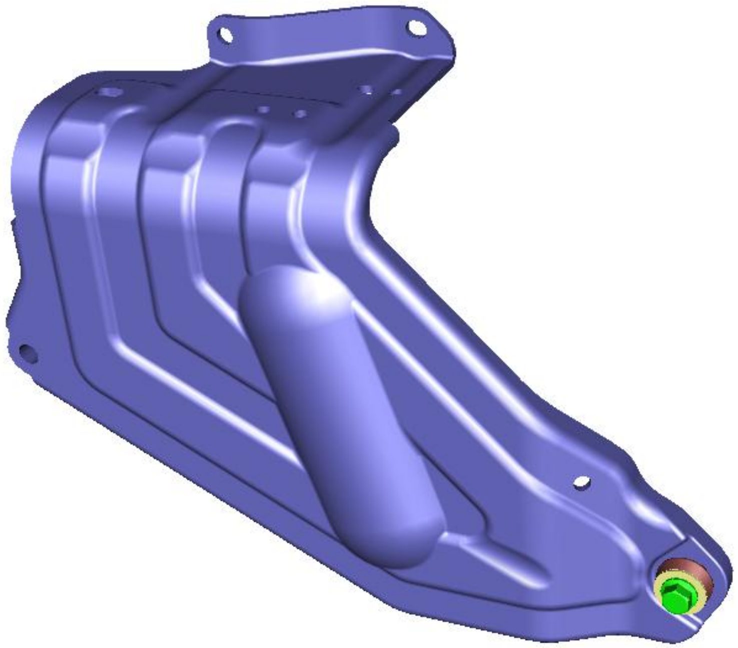
Design Optimization:

“ Flash Bainite 1500 “
replacing
High Strength Steel GMW3032M-ST-S HR550LA U

November 2, 2015



Jeff Mantey - Design Engineer

Steven Kwong – Material Engineer

Tom Prell – Safety CAE Engineer - Omega

Daniel Meza – Performance Engineer - Alpha

Lance Abbotts – Technician Drop Silo

Kevin Leitch – Technician Drop Silo

Team Roster

Position	Name(s)	Responsibilities
Team Leader DFSS project credit	Jeff Mantey (DRE)	Develop project plan Execute project – deliver on time and to plan Schedule and lead team meetings Generate and maintain standard project documentation Communicate project progress / status to Sponsor and DFSS Coach
DE / DRE / Subject Matter Expert	Steven Kwong (Material Engineer)	Provide design data Assignments in area of expertise
Critical Project Contributor DFSS project credit	Steven Kwong (Material Engineer) Tom Prell (Safety Engineer) Daniel Meza (Performance Engineer) Lance Abbotts (Technician Drop Silo) Kevin Leitch (Technician Drop Silo)	System models, create and exercise math model(s) / transfer function(s) Generate experimental data to create / validate transfer function(s)
Quality	n/a	Quality data from plant, supplier, etc., gage R&R, process capability Warranty analysis, JDPower data
Manufacturing	n/a	Manufacturing data, expertise, BOP expertise
BOM Family Owner (BFO)	Matt Hamilton	Group and present project results into product and process learnings Identify any new engineering tasks, methods, analysis procedures, tools or instructions to appropriate expert team
Statistical Support	n/a	Statistical expertise, DOE, reliability tools, and Response Surface methodologies
DFSS Coach DFSS project credit	Steven Kwong (Materials)	Coach the Team Leader, train the team, assist in team startup, attend team meetings, participate in all DFSS technical reviews
Engineering Center Sponsor (Director)GFL DFSS project credit	John Douro (EGM)	GM management that will review the finished work. Owner of the resources to get the project done.

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Project Charter

Engine Program(s)*	HFV6 Gen2+
Model Year(s)*	2020
Vehicle Line(s)*	Omega, Alpha, Mid Size Truck

SMT or Integration Area*	Powertrain / Vehicle
QRD Focus Area*	Fuel Delivery / Other
BOM Row #*	

Start Date (proposed or actual)	09-Feb-2015
Targeted End Date	01-November-2015
Required End Date	01-November-2015

Champion (Exec. Director)	Mike Anderson
Program Sponsor	
Engineering Center Sponsor (Director)	John Douro

This information* is required to post completed DFSS projects in GDM.

Opportunity Statement / Expected Outcome

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Opportunity Statement:

- Mass Savings over current material released on MY2016 HFV6 Gen2 Fuel Barrier Shield Part number #12673614 3mm thick and weighs 1.36kg

What's in it for the customer, what is in it for GM?

- For the Customer - Lighter Engine / Vehicle – better Fuel Economy
- For GM – Lighter Engine / vehicle and Potential Cost Savings
    - Platform Structures opportunities

Expected Outcome (Specific Deliverables to the program):

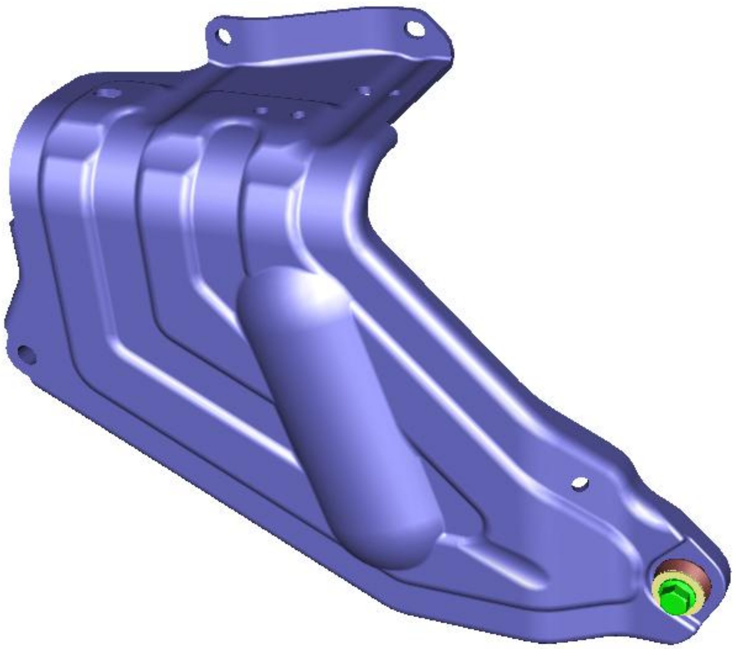
- Prove that Flash Bainite at 2mm (possibility 1.6mm – stretch target) can perform as well as 3mm of High Strength Steel
- Possible Cost Saving

Constraints:

- Must pass all requirements in a Vehicle Barrier Crash

Baseline Design (Current)

Current MY2016 HFV6 Fuel Barrier Shield #12673614
Material = High Strength Steel GMW3032M-ST-S HR550LA U
Thickness = 3mm   Mass = 1.36 Kg (3 lbs)



Data Support for Identified Opportunity

What is Flash Bainite Material and Process

FLASH BAINITE
MAXIMUM STRENGTH STEEL

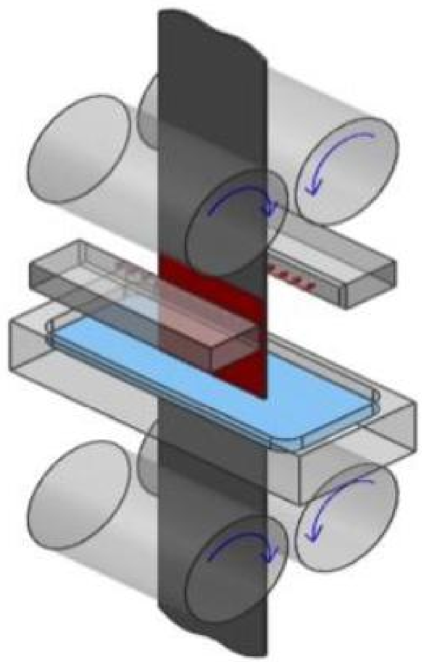
What is *Flash® Processing?*

... Flash Processing starts with commercial off the shelf steels like AISI1010, 1020, or 4130

... using Induction Heating technology the steel is rapidly heated in approx 2-3 seconds to temperatures over 1000C, typically 1070C to 1200C

... within a few seconds, the austenized steel is quenched with a water spray or bath.

... by limiting austenization time, the natural heterogeneity of the steel is preserved to create an engineered micro-segregation of both chemistry and phase in a matrix that combines the strength of martensite with the ductility of bainite.



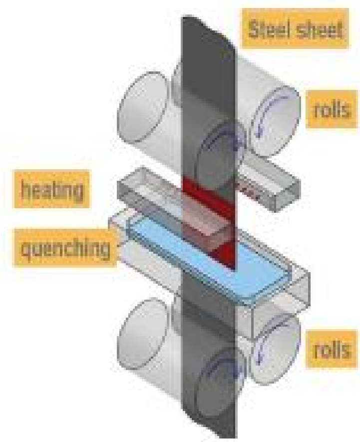
Data Support for Identified Opportunity

What is Flash Bainite Material and Process

FLASH® BAINITE
MAXIMUM STRENGTH STEEL

SFP Works, LLC has developed and globally patented a rapid heat treating ***process technology*** for the 21st Century Steel industry. Flash® Bainite Processing creates an engineered micro-segregation of both chemistry and microstructural phase at the micron level. Validated by Ohio State University - Industrial Welding Systems Engineering and US Army ARDEC Labs, Flash® Bainite Processing creates **"Maximum Strength Steel" with unmatched ductility and toughness.**

Costly alloying and time consuming, capital intensive thermo-mechanical processing are not needed. Equipment costs are scalable based on product size and annual throughput desired. Creating a paradigm shift in the domestic AHSS supply chain, **Flash® Bainite Process <u>LICENSING</u> is available for use at OEM/Tier 1 locations.**



COTS Alloy	Flash® Yield	Flash® Ultimate
AISI1010	850MPa	1100MPa
AISI1020	1150MPa	1500-1600MPa
AISI4130	1400MPa	1800-1900MPa
AISI4140	1550MPa	2000-2100MPa

According to the US Army ARDEC Technical Report of 22Feb2011 by Benet Labs / Picatinny Arsenal

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Data Support for Identified Opportunity

What is Flash Bainite Material and Process

According to the US Army ARDEC Technical Report of 22Feb2011 by Benet Labs / Picatinny Arsenal

> ***"… the Flash® Bainite 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."***

The proprietary **Flash® Process transforms tubing and sheet/plates** from <1mm to 10mm thickness with minimal distortion. Flash processing is continuous, thus compatible with most steel forms (coil, bar, structural shape) and rolling practices. **Pre-formed components such as frame rails, roof bows, and bumper beams can be Flashed.**

- **Formable to Zero-T / 1T bend radii up to 1550MPa . . . even Secondary Ops!**
- **Readily available input alloy . . . just plain carbon steel for >1500MPa**
- **Spot, laser, and GMAW weldable with standard factory floor procedures.**
- **Soft steel can be roll-formed . . . then strengthened with minimal distortion.**
- **Hydro-formable to reasonable sweeps and complex cross sections**
- **Flash Processing costs only about $0.15 per pound in full production.**
- **Low cost Flash Equipment can be installed at the OEM/Tier 1 location**

Lacking the unknowns of "exotic" materials, costly changeovers, new manufacturing processes, long term durability, and insurance repairs, **Flash® Bainite Steel provides greatly enhanced Structure and Safety for both civilian and military applications.**

Gary M. Cola, Jr. gary.cola@flashbainite.com ***586.864.9001***
President & Chief Technology Officer *R11: 22Oct2014*

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Test Setup Details (Current material and Flash Bainite)

Testing – High Strength Steel HR550LA vs Flash Bainite

Material property testing conducted at GM Material Labs in Warren, Michigan

- Evaluate Tensile bars made to Flash 1500 at 1.27mm, 1.6mm and 2.0mm thickness

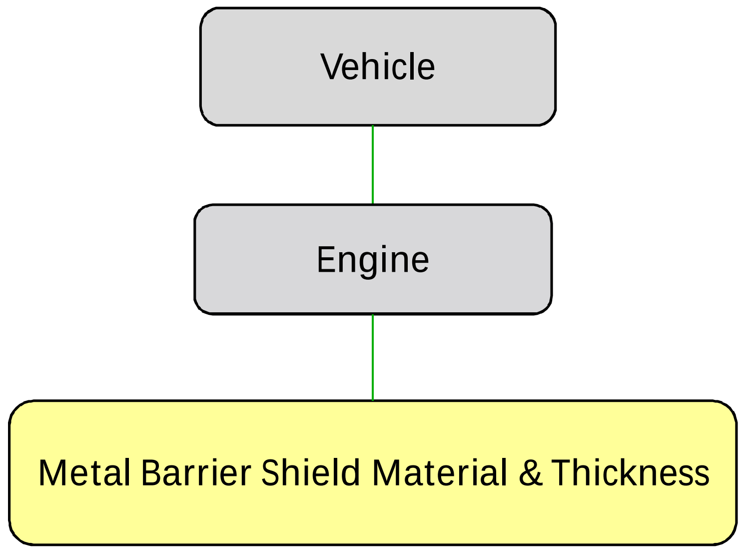
Computer Simulation of a Vehicle Barrier Crash Event

- Use Omega Platform with HFV6 Gen2 LGX Engine using USNCAP and IIHS Offset simulations
- USNCSP = *United States New Car Assessment Program*
- IIHS Offset = *Insurance Institute for Highway Safety*

Drop Silo Testing (MPG – Component Test Lab - Building 25)

- Evaluate current production Barrier Shield 3mm vs Flash Bainite shields at 1.27, 1.6, 2.0mm

Scope / System Boundaries



- Out of Scope
- In Scope (OK to modify)

Parameter Diagram

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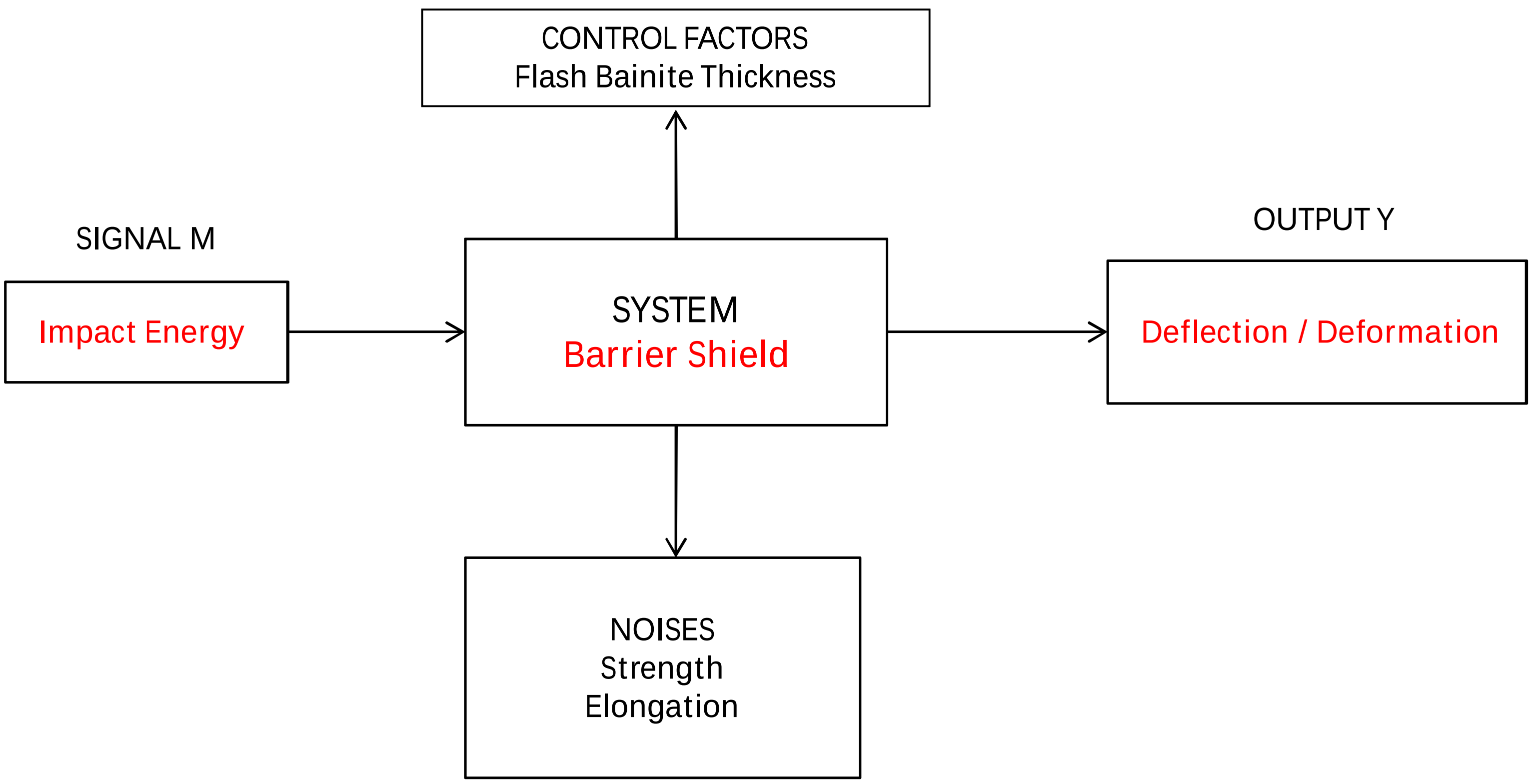

Data Support for Identified Opportunity

Some of the Flash Bainite Material Samples evaluated in GM Material Lab in Warren, Michigan

Data Support for Identified Opportunity

Flash Bainite material samples tensile tested at GM Material Lab in Warren, Michigan

Material	UTS (Mpa)	Yield Strength (Mpa)	Elongation (%)
Current (HR550LA)	687	645	24.5
FB1500 (2.0mm)			
Average	1550	1171	8.0
+/- 3σ	1566 / 1533	1226 / 1116	9.3 / 6.8
FB1500 (1.6mm)			
Average	1537	1160	7.1
+/- 3σ	1563 / 1512	1221 / 1100	8.4 / 5.8

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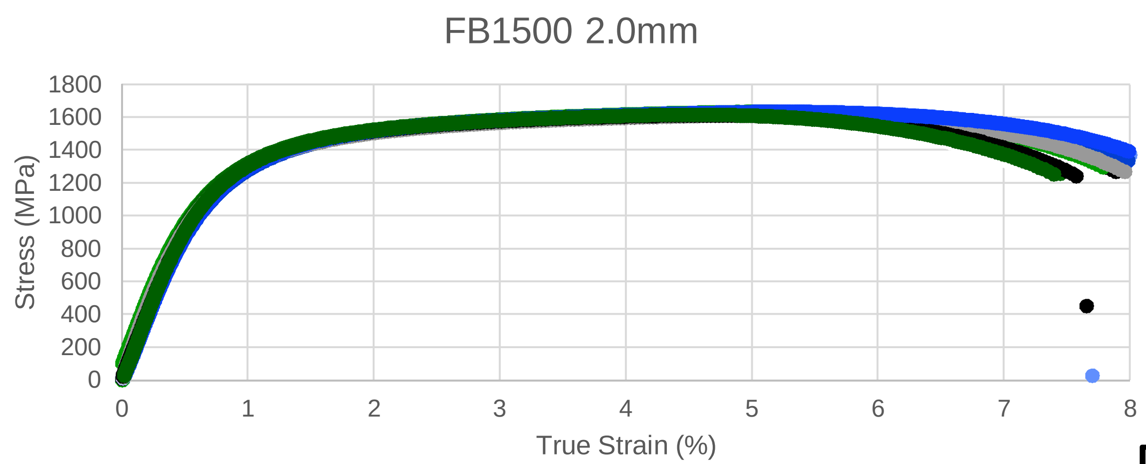
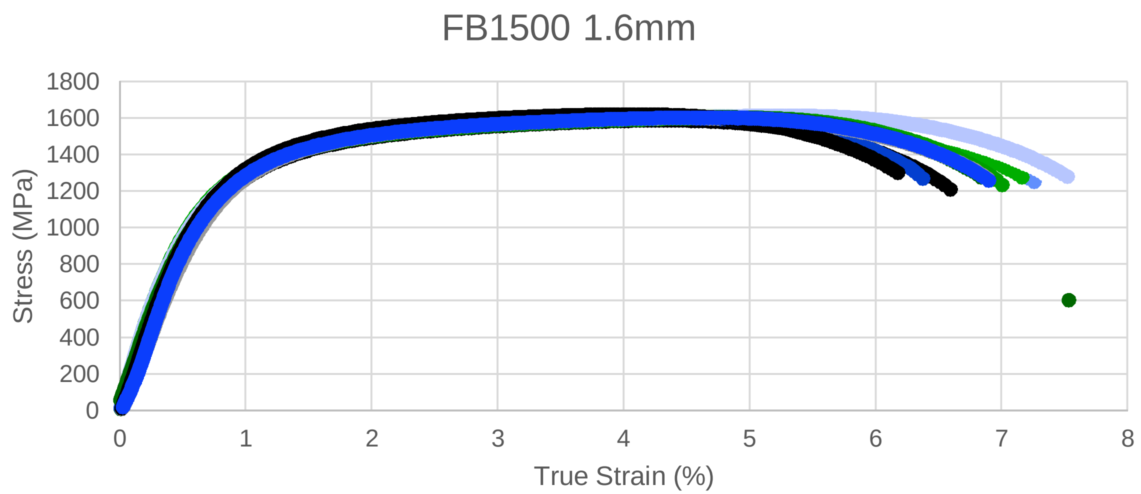
<u>Flash Bainite material samples tensile tested at GM Material Lab in Warren, Michigan</u>
<u>Testing per ASTM E8 Standard</u>

12 samples
Report #WRN1501534



11 samples
Report #WRN1502979



Tensile properties consistent.

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Test Setup Details
(Current material and Flash Bainite)

CAE Results

Comparing 2mm Flash Bainite
with
3mm High Strength Steel GMW3032M-ST-S HR550LA U

Tom Prell - Vehicle Safety CAE

Analytical Assumptions

LGW / LGX Fuel System Shield

- Analysis was performed on the O1SL TKV107 model in the USNCAP (56 Kph) and IIHS Frontal Offset (64 Kph)
- Analysis is an "A to B" comparison to determine potential feasibility
- This is preliminary and does not apply to all architectures

  - Tom Prell – Vehicle Safety CAE

Analytical Results

LGW/LGX Fuel System Shield

CAE Results:
- USNCAP – performance between baseline and proposal is essentially the same.
- IIHS Offset – performance of proposal is slightly degraded but model predicts the sensitive fuel system components are protected.

Conclusion :

CAE data supports the feasibility, however, component level testing would be beneficial to support CAE. Performance Team may require barrier test.

Tom Prell – Vehicle Safety CAE

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High Strength Steel vs Flash Bainite

Computer Simulation of a Vehicle Barrier Crash

Omega Platform vehicle
with
HFV6 Gen2 LGX Engine
using USNCAP and IIHS Offset simulations

Final CAE Results

The two CAE simulations results shows that
Flash Bainite material at 2mm
performs as well as 3mm of High Strength Steel

Drop Silo Testing - MPG

Four Shield thickness's to be "Drop Silo" tested

3.0mm
MY2016 HFV6 Gen2 Barrier Shield #12673614
High Strength Steel GMW3032M-ST-S HR550LA U

2.0mm
Prototype Bainite Flash 1500

1.6mm
Prototype Bainite Flash 1500

1.27mm
Prototype Bainite Flash 1600

Example of Flash Bainite part

Drop Silo Testing - MPG

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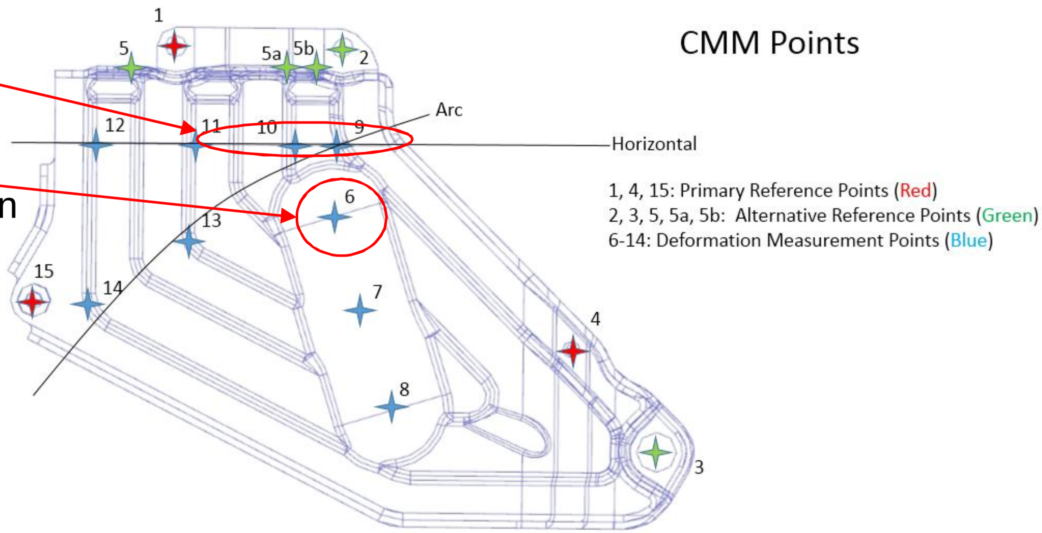
Coordinates CMM checked before and after each test
There were 2 test locations

- Drop Head Location 1 = Based on the Omega Vehicle Computer model simulation for point of impact
- Drop Head Location 2 = Expected point of significant deflection
- Four Thickness evaluated 3.0mm, 2.0mm, 1.6mm, 1.27mm

Drop Head Location 1
Based on the Omega Vehicle Computer model simulation

Drop Head Location 2
Expected point of significant deflection



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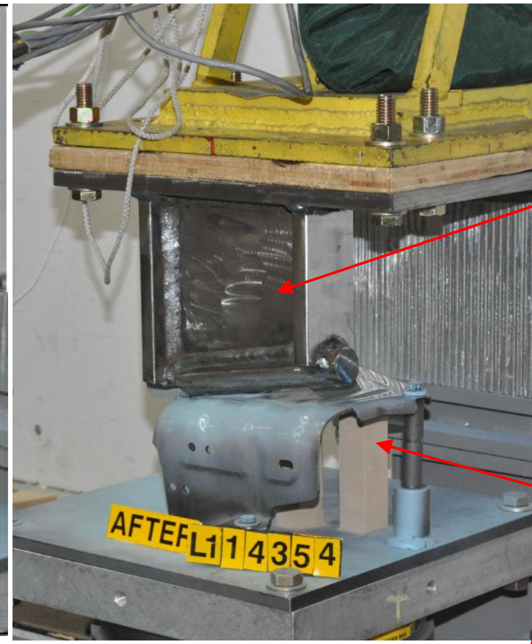
Drop Silo Testing - MPG

Pre-Test setup
Pass Binary



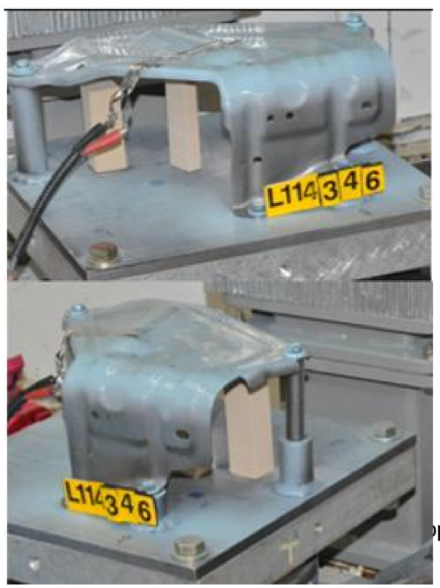
Drop Head

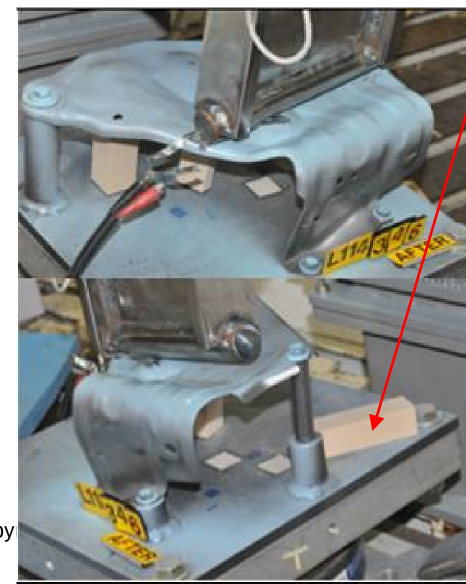
Post Test setup
Pass Binary

Frangible Foam blocks represent Fuel System components being protected by Barrier Shield.

They are positioned with the exact clearance to the Fuel Pump and left hand / right hand Fuel Rails.

Pre-Test results
Fail Binary





Post Test setup
Fail Binary

Drop Silo Testing - MPG

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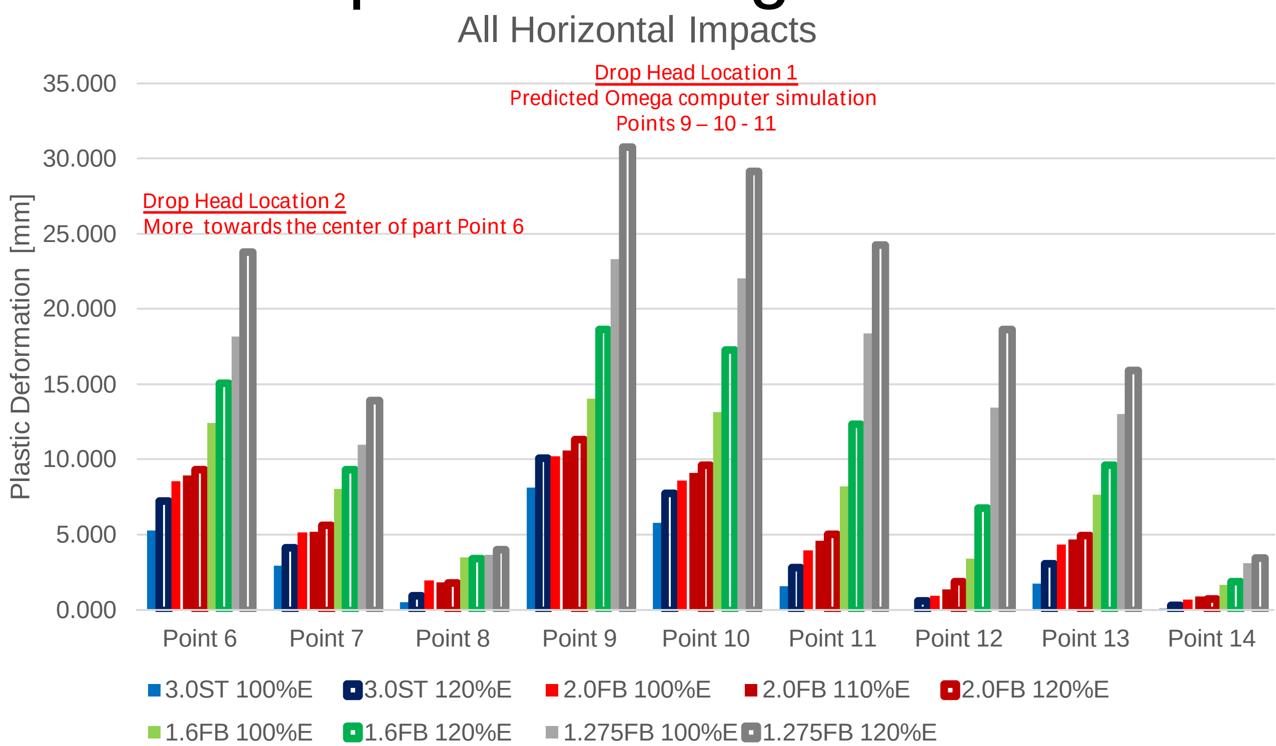

Pass Binary		Binary Not Tested Material limit testing				
Fail Binary						
	H-100	H-110	H-120	C-100	C-120	C-500
3.0mm	L114352		L114353	L114350	L114351	
2.0mm	L114354	L114355	L114356	L114347	L114348	
1.6mm	L114357		L113820	L114349	L114345	
1.275mm	L113821		L113822	L114346		L113823

H-100 = CAE predicted hit location
100% of predicted energy from CAE model

H-110 = CAE predicted hit location
110% of predicted energy from CAE model

H-120 = CAE predicted hit location
120% of predicted energy from CAE model

C-100 = Hit towards Center of Shield
100% of predicted energy from CAE model

C-120 = Hit towards Center of Shield
120% of predicted energy from CAE model

C-500 = Hit towards Center of Shield
500% of predicted energy from CAE model

Pugh Analysis

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Option	Strength	Mass	Cost	FEA Crash-worthiness	Drop Silo performance*
Current Material (3.0mm thick)	0	0	0	0	0
FB1500 (2.0mm thick)	++	+	?	0	0
FB1500 (1.6mm thick)	++	++	?	? **	0
FB1600 (1.27mm thick)	++	+++	?	? **	--

*Based on "Drop Silo" Binary design of experiments
*100% energy
*Computer model simulation for point of impact

**Future RLM project

I D D O V

Benefits & Implementation

- Lighter Weight Engine / Vehicle
- Potential Cost Savings
- Material potential in many other vehicle applications

- Design MY2020 HFV6 Gen2+ Barrier Shield at 2mm thick or less
  - Beta Engine – Summer 2016
  - SOP September 2019 (MY2020)

- Validation
  - Drop Silo Testing (September / October 2015)
  - FEA Analysis Simulating Barrier Crash (2015 / 2016)
  - Vehicle Barrier Testing (2017 / 2018)

Form Revised 5/30/12

Knowledge Capture & Share

I D D O V

- DFSS will be reviewed in Fuel Delivery PMT
  - Scheduled for November 1, 2015
  - DFSS will be shared with Materials Group
  - DFSS will be shared with Vehicle teams
  - DFSS will be stored on GDM

- Key learnings:
  - New Material for Engine / Vehicle usage that is …
    - Stronger and Lighter than today's High Strength Steel
      - Similar performance with less thickness
    - Potentially less expensive than MY2016 HFV6 Gen2 Barrier shield 12673614 High Strength Steel for final piece cost
      - Raw material cost for Flash Bainite is less

Recommended Future Work

- Evaluate other applications for Flash Bainite material
  - There are other brackets at Powertrain and Vehicle structural components that could be considered
- Start a RLM (Road Lab Math) project
  - Intensive material testing (Improve DYNA 3D material model)
- Start computer modeling of the Drop Silo "Drop Head"
  - Correlate physical testing CAE results
- Rerun the Omega Vehicle / Alpha / Midsize Truck = "computer simulated barrier crash"

Summary

- Computer model of a Omega Vehicle Barrier test show that 2mm Flash Bainite performs as well as 3mm of High Strength Steel
- Physical testing (Drop Silo) results show that Flash Bainite at 1.6mm performance was equivalent to the 3mm high strength steel with regards to binary test design

- Flash Bainite vs MY2016 Production Barrier shield at 3mm
  - 1.275mm ⇨ 58% thinner ⇨ saves approx. 0.XX kg (1.74 lb)
  - 1.6mm ⇨ 46% thinner ⇨ saves approx. 0.61 kg (1.3 lb)
  - 2mm ⇨ 33% thinner ⇨ saves approx. 0.45 kg (0.99 lb)

- Benefit to GM
  - Potential Cost savings
  - Another material in its catalog to use in its continuing effort to design lighter weight Engines / Vehicles at a reduced cost.

- Acknowledgment
  - **Gary Cola – President of SFP Works, LLC**

Data Support for Identified Opportunity

Company

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