

Great Designs in

# STEEL



Diversitak, Inc.



ArcelorMittal

## Door Lightweighting Using Ultra-Thin AHSS Reinforced with Low Density CFRE Materials

Sriram Sadagopan

ArcelorMittal

# Project Team

## ArcelorMittal

Sriram Sadagopan, Michael Lizak, Min Kuo, Rodney Robison

## Diversitak

Rajan Eadara , Todd Brewer, Jeven M Joseff , Gerald Cole, A. Joseff

## Oak Ridge National Laboratories

Charles David Warren

## Idaho National Laboratories

Gabriel Ilevbare, Timothy Yoder

# Project Objective

- Continue exploring lightweighting opportunities with steel used in conjunction with carbon fiber reinforced epoxy
- Target immediate studies for closure panel materials
  - Doors
    - 0.6mm DP490
    - 0.55mm DP490
    - 0.5mm DP490
- Conduct comparative dent and oil canning testing

# Carbon Fiber Reinforced Epoxy

- Carbon fiber reinforced epoxy composite (patent approved)
- Robotically applied with spray, swirl, or shovel applications
- Cures at 150<sup>0</sup>C to 200<sup>0</sup>C
- The material forms into a high modulus coating on the steel substrate after curing
- Compatible with typical automotive assembly processes

- Achieve overall panel weight reduction while maintaining the same structural performance
- Robotic application of the product, instead of the current practice of manually applied patches
  - Increased precision and repeatability of product application
  - Cost and weight savings
  - Increased panel design flexibility

# Material Properties

- Steels Used: HDG DP490

Thickness(mm)/ Weight(kg)	YS (MPa)	TS (MPa)	UE (%)	TE (%)	n-bar	R-bar
0.5/4.94	368	538	16.8	27.3	0.17	0.92
0.55/5.44	369	523	17.0	28.9	0.17	0.94
0.6/5.95	378	509	16.1	26.7	0.16	1.0

- Typical Properties of CFRE

- Lap Shear Strength: 16 MPa @ 23°C
- As Received Peel Resistance: 7800 N/m
- Density: 0.9 g/cc
- Elastic Modulus: 2-4 GPa

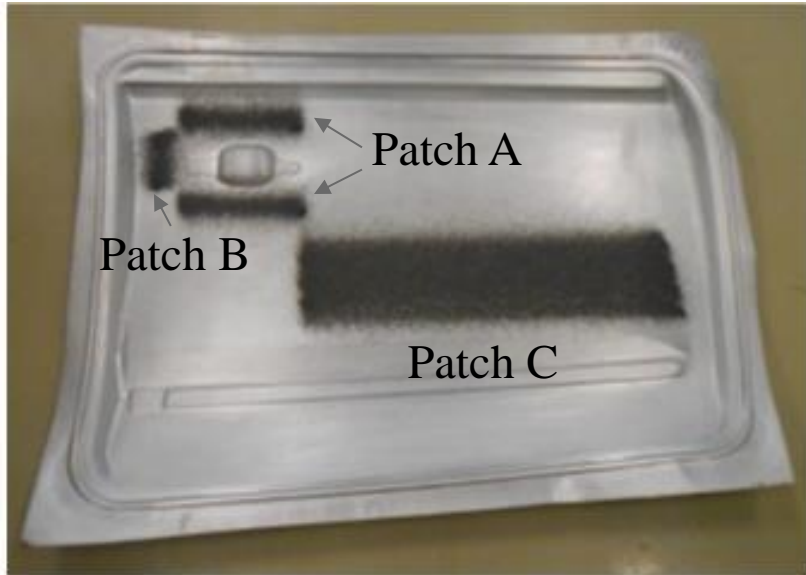
- Door skins stamped by ArcelorMittal
- Application of CFRE in selected areas
  - CFRE Thickness
    - 0.5mm - 1.0mm on selected areas
    - 0.5mm applied on the entire door panel
- Simulate inner structure by fabricated fixture
- White light scanning and comparison with baseline for assessment of read-through
- Dent and oil canning testing at several locations

# Stamped Door Outers





# Reinforcement Application Areas



- The areas shown above were reinforced as they might be the most susceptible to denting damage.
- Two thicknesses of patches were considered: 0.5mm and 1mm

Mass addition to door (gm)

	0.5mm	1.0mm
Patch A	12.58	25.16
Patch B	5.24	10.48
Patch C	97.29	194.58
<b>Total</b>	<b>115.11</b>	<b>230.22</b>

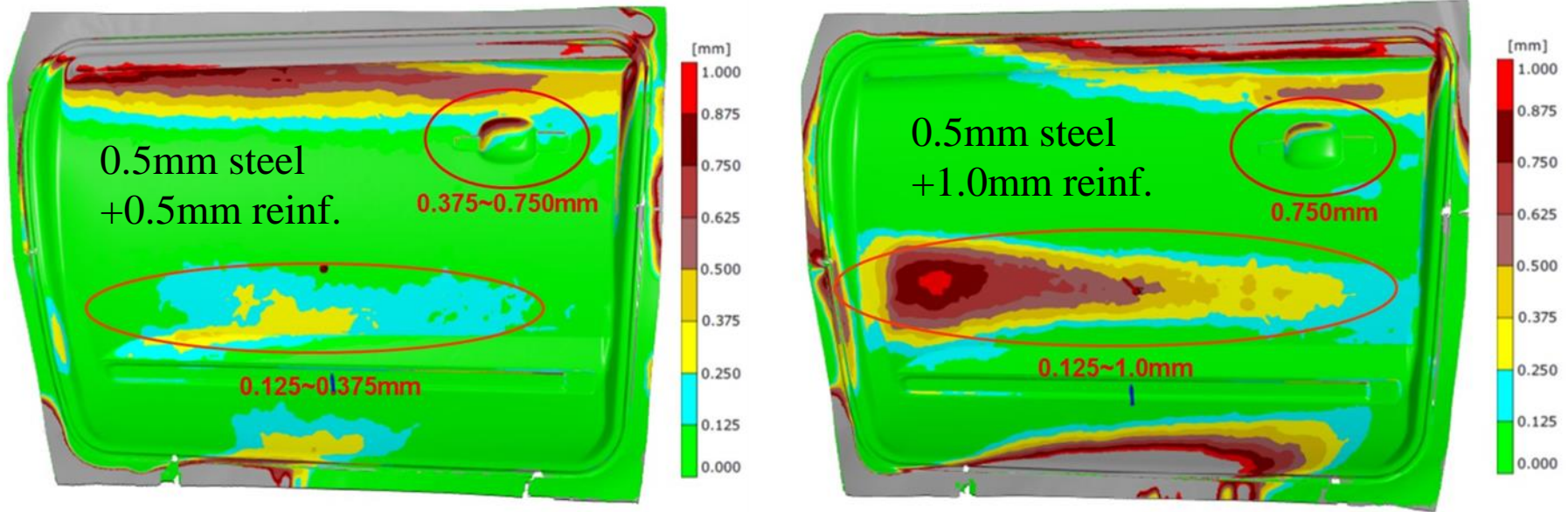
# Reinforcement Application Areas

- Complete coverage of door
- Optimized density of reinforcement materials
  - CFRE
    - Mass added ~ 450gm
- Panels painted for visual evaluation of read-through
- Focus on oil canning performance



# White Light Scanning of Panels

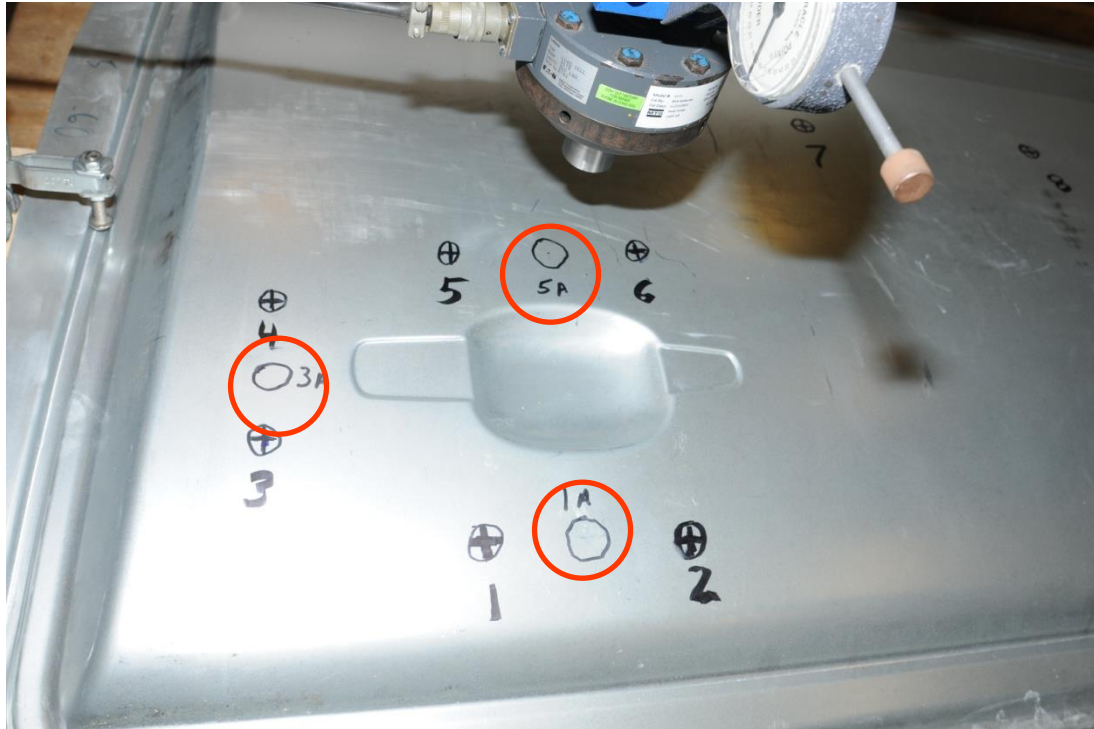
## Comparison with Reference



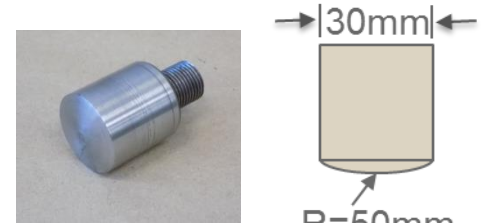
- Thicker patch causes more surface deviation from the baseline outer skin, particularly in the relatively flat central area.

# Test Locations

Middle of the reinforcement patch



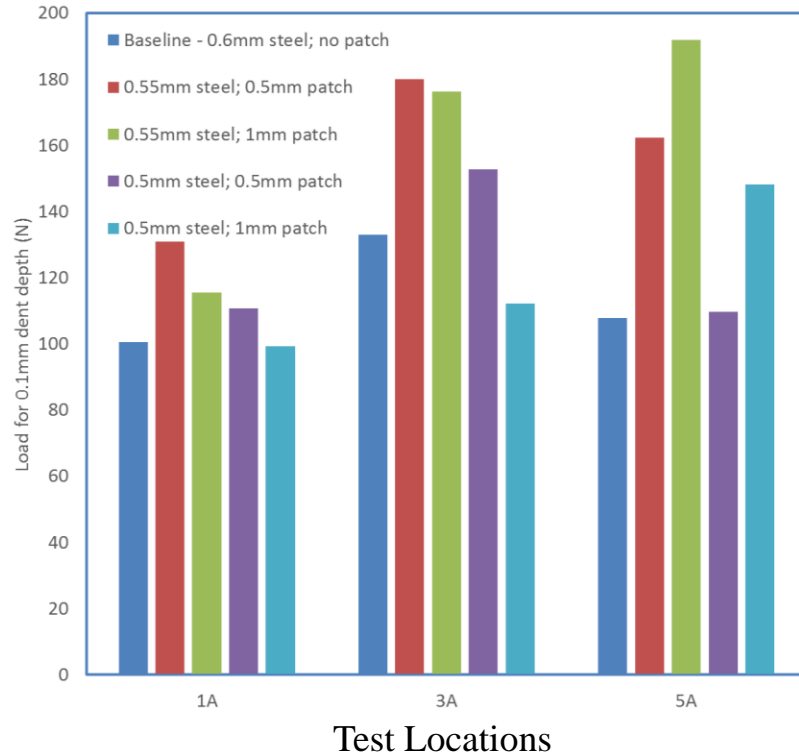
Dent testing indenter



Oil canning indenter

# Dent Testing: Summary

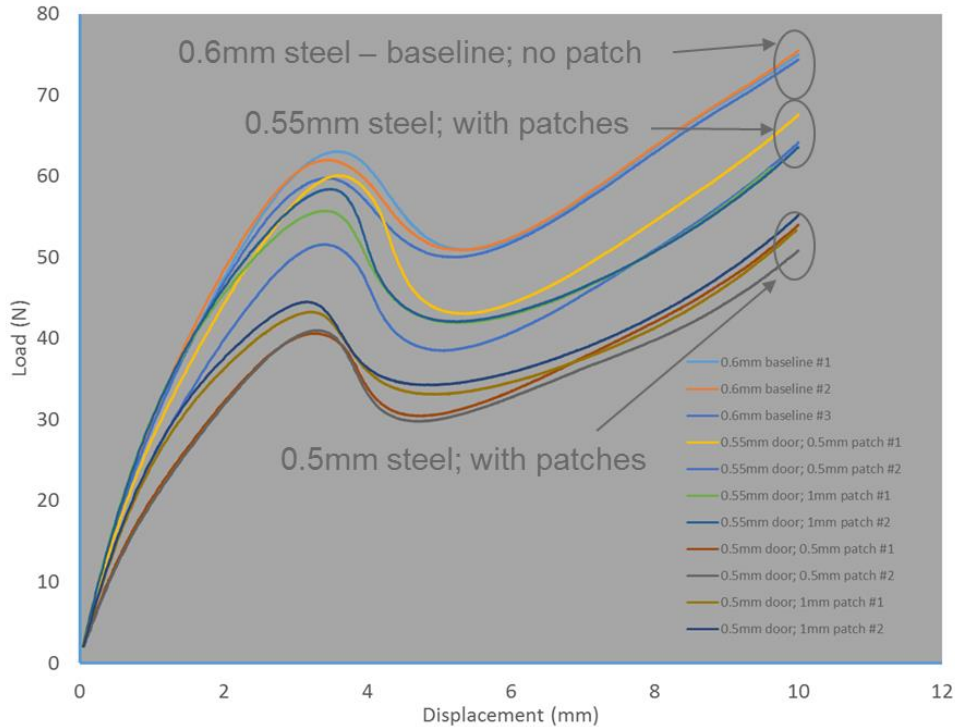
## Comparison with a mass-efficient baseline



- Use of the reinforcement patch improves dent resistance
- Dent resistance of 0.5mm door skin with reinforcement was comparable to the baseline of 0.6mm
  - Results are location specific because of local conditions

# Oil Canning Testing: Location 5A

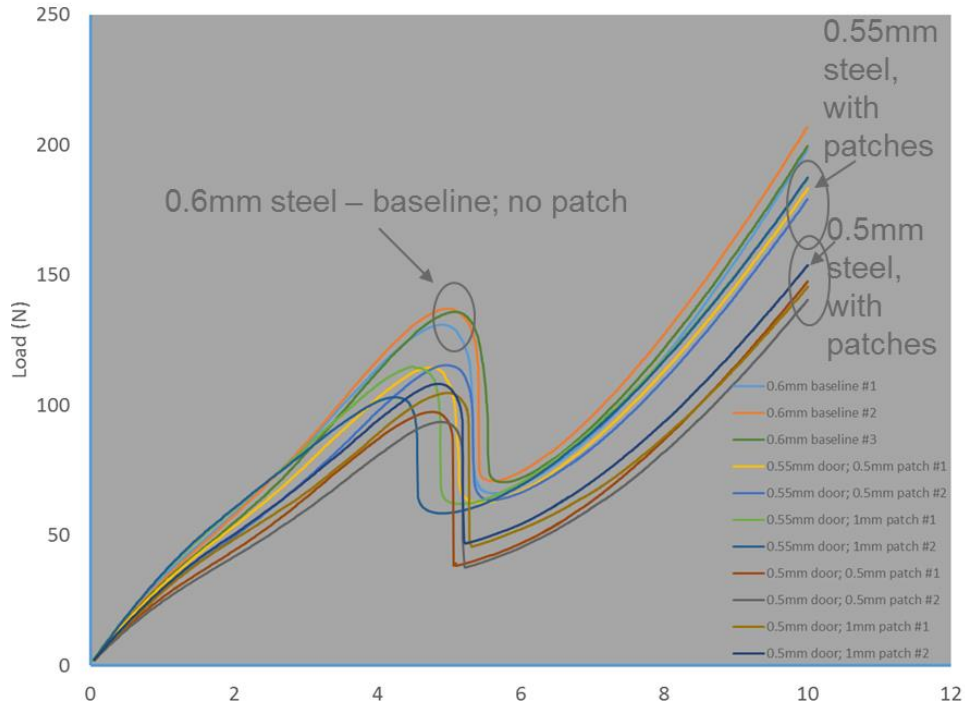
## Comparison with mass-efficient baseline



- Use of local patches are not effective in increasing oil canning resistance
- Need to increase CFRE coverage area to meet oil canning requirement

# Oil Canning Testing: Location 1A

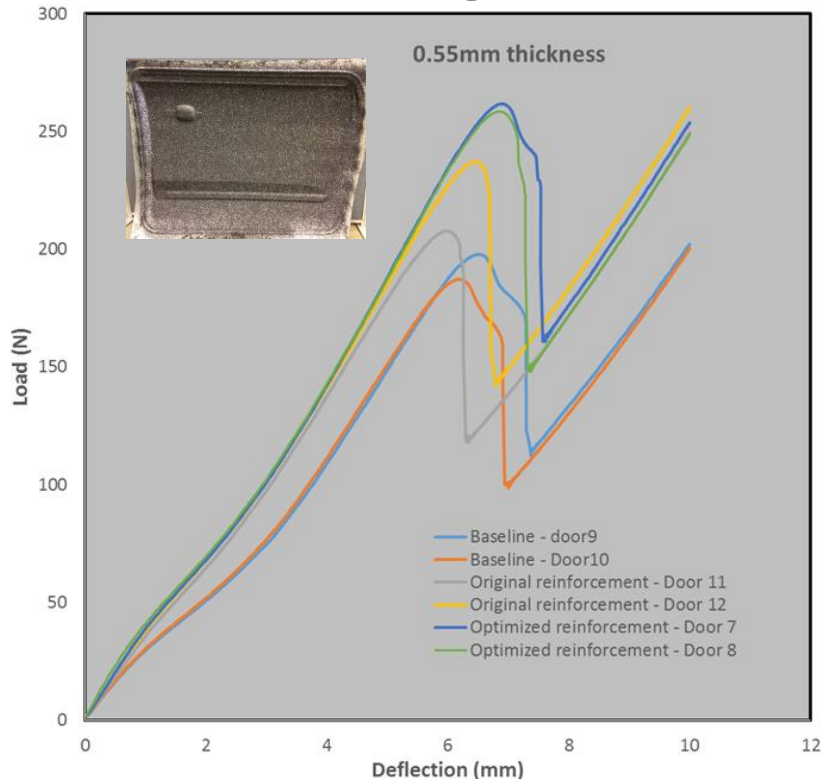
## Comparison with mass-efficient baseline



- Use of local patches are not effective in increasing oil canning resistance
- **Need to increase CFRE coverage area to meet oil canning requirement**

# Oil Canning Testing: Location 1A

## Full door coverage with CFRE



- Full coverage CFRE application results in better oil canning performance
- Optimized CFRE formulation results in improved repeatability
- Validation with OEM specific requirements would be necessary



# Learnings Thus Far

- In comparison with a mass efficient benchmark, local reinforcements were effective in improving dent resistance of tested areas
- In comparison with a mass efficient baseline, the improvement of oil canning resistance was not enough to offset the reduction in thickness with local reinforcements
- Higher improvement in oil canning behavior with the full application (entire door) of reinforcement material

# DOE LightMAT – Steel Panel Weight Reduction

- DOE LightMAT – Automotive Panel Weight Reduction with High Strength Steel and Carbon Fiber Reinforced Epoxy
- ArcelorMittal and Diversitak were jointly awarded a grant working with US National Labs
- Objectives of the study
  - Aggressive lightweighting using a combination of steel and CFRE
  - Optimize C Fiber formulation to reduce cost impact

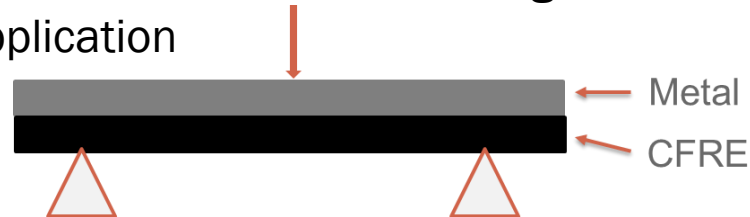
## Carbon coat it – DOE Press Release, August 2017

ArcelorMittal, a multinational steel products company, and Diversitak, a Detroit-based automotive polymer material manufacturer/supplier, will team with experts from Oak Ridge and Idaho National laboratories to reinforce very thin sheets of advanced high strength steel with a carbon fiber epoxy coating and conduct component testing. Advanced high strength steel can be made into very thin, lightweight panels but are challenged to meet stiffness performance required by automotive manufacturers. Carbon fiber reinforced epoxy application will help achieve these desired targets. ORNL's carbon materials expertise and INL's chemistry, metallography and high-resolution imaging capability will help the partners develop and ensure the integrity of the interface between the coating and steel.

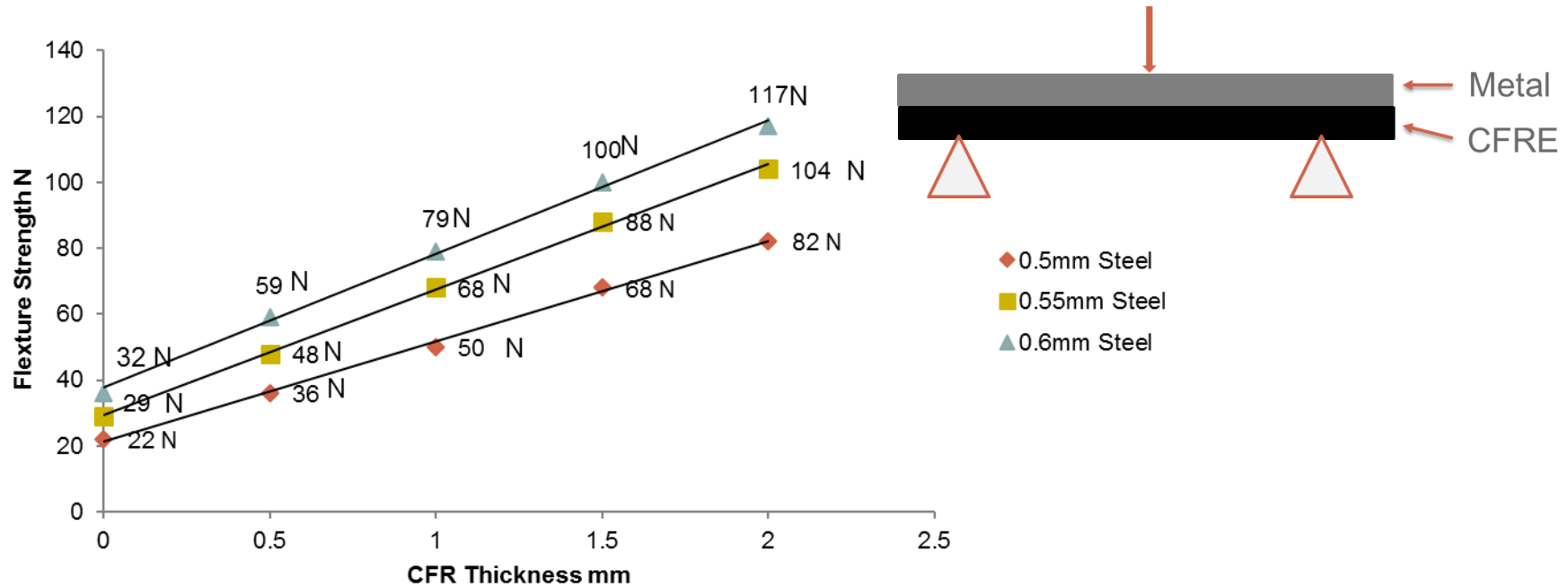
# Flexural Strength (N): 0.5mm CFRE Application

C-Fiber content % by wt.	Fiber length (micron)	Steel Thickness(mm)		
		0.5	0.55	0.6
Steel only	--	22	29	32
Epoxy no fiber	--	25.22	32.37	36.18
15	100	36.0	48.00	59.00
20	100	38.31	44.81	55.26
25	100	37.36	45.38	54.72
15	200	36.69	38.56	54.14
20	200	38.04	44.01	56.62
25	200	38.46	48.64	56.88
15	400	37.07	38.67	53.14
20	400	39.98	45.95	55.16
25	400	39.12	45.12	56.47

- Fiber length of 100micron is sufficient for flexural strength and would also be easier for robotic spray-on application



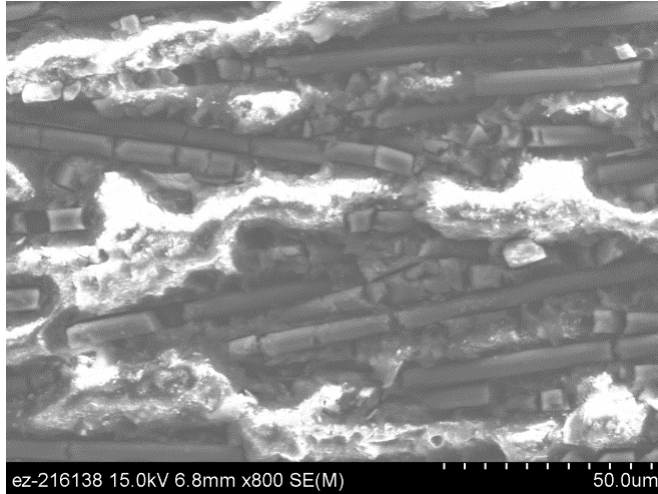
# Flexural Strength VS CFRE Thickness



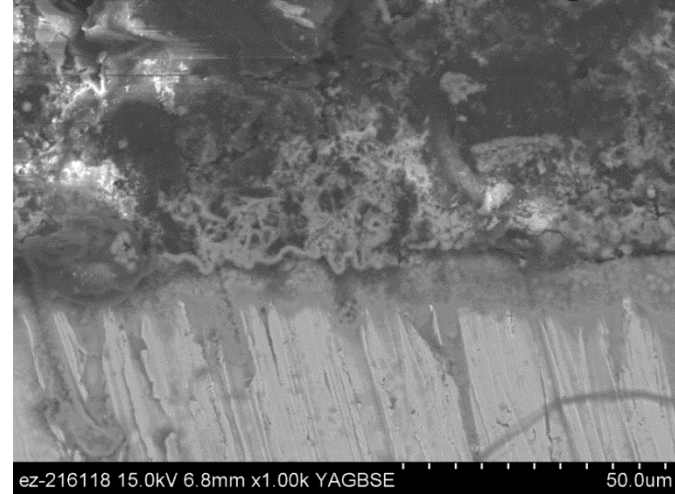
Linear relationship between flexural strength and CFRE thickness

# SEM Characterization: ORNL Data

100 micron fiber length



400 micron fiber length



- 100 micron fibers are more uniformly distributed in the epoxy matrix
- 400 micron fibers tend to float to the surface of the epoxy during curing

# Summary of C Fiber Optimization Study

- Without carbon fiber in the epoxy, there is no improvement in the flexural strength of the panel
- The strength enhancement differences are minimal between different ratios of fiber in the epoxy
- Average flexural strength improvement between blank panel and 0.5 mm CFRE coated panels range between 50% to 70% higher.
- Increase in flexural strength is linear with the increase in the applied thickness of CFRE
- Effect of carbon fiber length on the flexural strength was not significant.
  - Better distribution efficiency of smaller fibers in the epoxy
  - 15% carbon fiber by weight is optimum in the formulation
  - 100 micron fiber would be a better choice for spray applications

# Conclusions

- Lower surface changes with 0.5mm CFRE application
  - More beneficial to use lower thickness reinforcement for minimization of panel read-through
- Local patch application may be sufficient for improvement of dent resistance
- For improvement of oil canning resistance it is necessary to increase coverage area
  - Improvement in dent and oil canning resistance was location-dependent
- Validation with OEM specific requirements would be necessary
- It is feasible to achieve aggressive lightweighting in automotive body structures using the right combination of high strength steel and optimized carbon fiber reinforced epoxy application
  - Compatible with existing manufacturing and assembly infrastructure

# For More Information

Sriram Sadagopan

ArcelorMittal

219.399.5593

Sriram.Sadagopan@arcelormittal.com

Rajan Eadara

Diversitak

313.530.6719

readara@dchem.com