A Vision for Carbon Fiber Composites (CFC) in Automotive

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Prediction is very difficult, especially if it's about the future.

Niels Bohr

Defining the Box for CFC

CFC have a future in main stream automotive market (Alternative fuel cars and low end large volume cars)

- Definition/Terminology
  - **CFC**: Carbon fiber reinforced polymer matrix based composite
  - **Automotive**: Passenger Cars, trucks, SUVs, law enforcement and Military vehicles (cars, trucks and SUVs)
- Why do we think the assumption is good? – Direct/Indirect impact
  - Direct: light weighting (Fuel price), part integration, crashworthiness (safety), design latitude, aerodynamics
  - Indirect: Packaging space, styling latitude, corrosion resistant
- Where CFC is used today?
  - Aerospace (civil and defense), Civil Infrastructure, Wind Energy, Printed Circuit Boards, Sports and Leisure, luxury/special cars, commercial vehicles

30 years of History…

- **Low volume, niche market**
  - **Mercedes *McLaren F1* (all Carbon monocoque structure and exterior body panels)**
  - **Ferrari *Enzo***
  - **Lamborghini *Murcielago***
  - **Porsche *Carrera GT***

Exterior body panels

- **Mass production passenger car applications (C-Fiber)**
  - **Ford – All Carbon *LTD* (1979; Weight savings 544 kg/1200 lbs)**
  - **GM – *Ultralite* concept vehicle (early 1990s)**
  - **GM – *Precept* gasoline/hybrid (circa 2000's)**
  - **GM – Corvette *LeMans Z06* coupe (2004 - exterior hood panel)**
  - **GM 2006 Corvette Z06 (switched to C-Fiber fender)**
  - **BMW M6 coupe – Roof panel**

Source: Automotive Composites

Vision of Future at current pace

◆ Polymer composites will have measurable but small presence in automotive in next few decades – primarily carbon fibers (CF) and glass fibers (GF)

◆ Several breakthroughs in polymer composites needed to attain parity with metal based solutions OR adoption as mainstream build material (automotive)

◆ Fuel efficiency - Carbon Fiber Composites (CFC) directionally right; Larger impact primarily due to

- ➢ Powertrain technology improvements
- ➢ Alternative Fuels

Bottlenecks for CFC acceptance

- **Primarily**
  - **Breakthrough associated with cost**
  - **Availability**
  - **Engineering confidence in car design (monocoque structures)**
  - **Highly integrated multifunctional features**
  - **High-throughput fabrication technology (prepreg tailored blanks, fast cure resin system, electric molding press etc)**
- **Secondarily**
  - **Ease of repair/assembly**
  - **Prototyping technologies comparable to metal stamping**
  - **Technology integration adaptability by OEM's**
  - **Thermoplastic matrix development**
  - **After-market parts**
  - **Recycling**

Why Composites?

- Is it impact on fuel efficiency due to mass reduction?
- Is it crashworthiness / Safety?
- Is it styling and part consolidation?
- Is it fuel efficiency due to aerodynamic design?

Mass Reduction and Fuel Efficiency

Rule of Thumb on value of less mass

- **Value for Money ($s & $ense) - Depends on "who you ask"**
  - Auto: 5-7$/Kg or ~2.5-3.5 $/lb
  - Aeronautical: 500–700 $/Kg or ~250-350 $/lb
  - Space: 5000-7000 $/Kg or ~2500-3500 $/lb

- **BMW – CFC Roof Design value proposition**
  - Aluminum 1.2 mm gage vs CFC 1.8 mm - Same performance
  - Weight savings – 1.1 kg
  - Value: $5.5-7.0/roof - max value $21K/year (3000 cars/yr platform)

Not a whole lot of value to share with Tiers!!

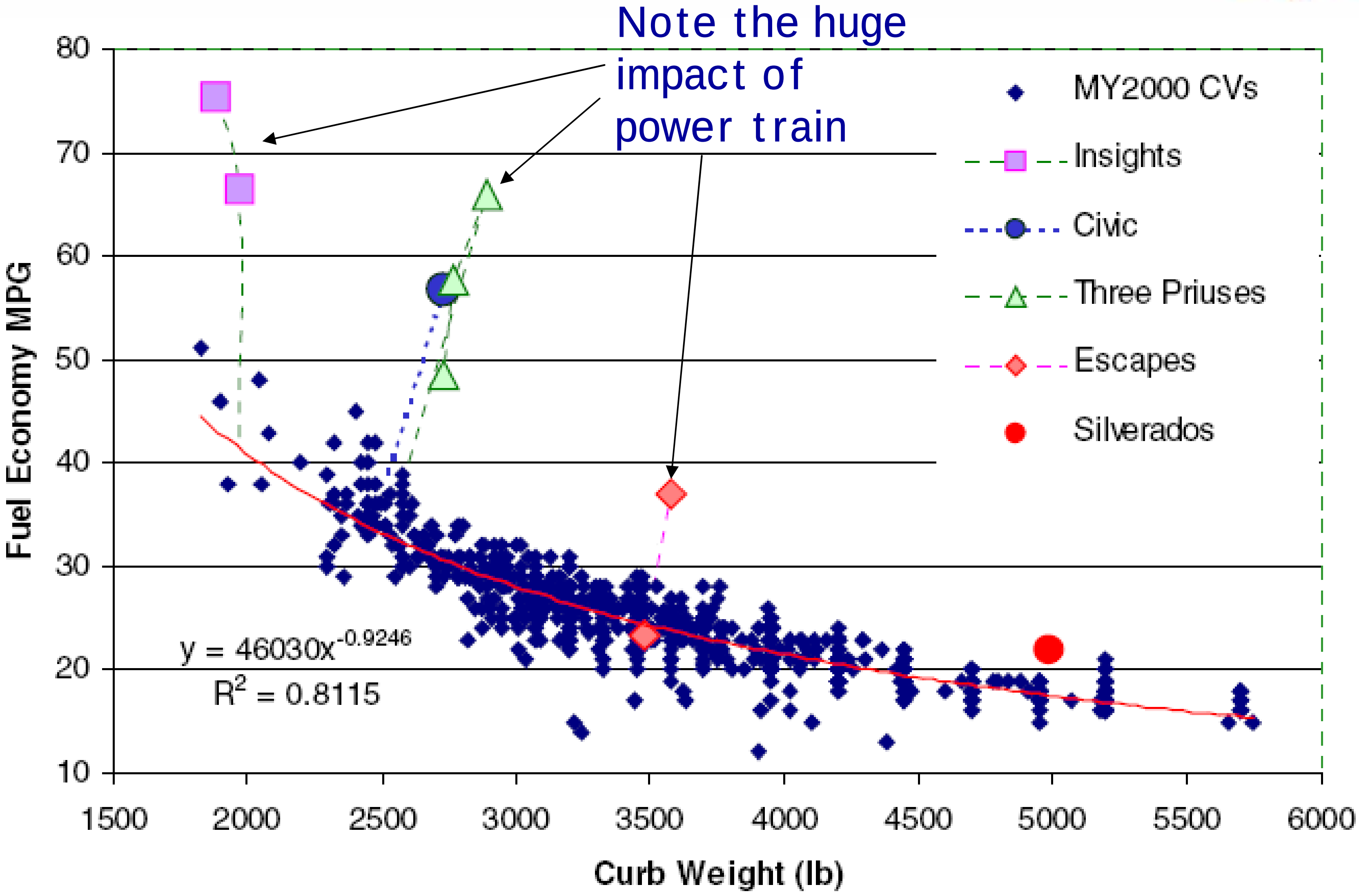
Where is the value? May be in heavier structural parts, consolidation…..!

Effect on Fuel Efficiency (Auto)

Design/Engine Type	Vehicle Weight (structure and closures)	Fuel Consumption (ltr. per 100 km) and (mpg)	Fuel Efficiency Increase
State of the Art	500 kg	10 (23.5)	0%
A) High strength steel plus structural bonding	350 kg (30%)	9.58 (24.6)	4.20%
B) Carbon fiber composite for structure and closures	270 kg (42%)	9.31 (25.3)	7%
C1) Diesel engine		7 (33.6)	30%
C2) Full Hybrid (Otto)		6.5 (36.2)	35%
C3) Full Hybrid (Diesel)		5.5 (42.8)	45%

Fuel efficiency improves but it cannot be the driver since changes in power train (PT) and fuel make a much bigger impact

Effect on Fuel efficiency



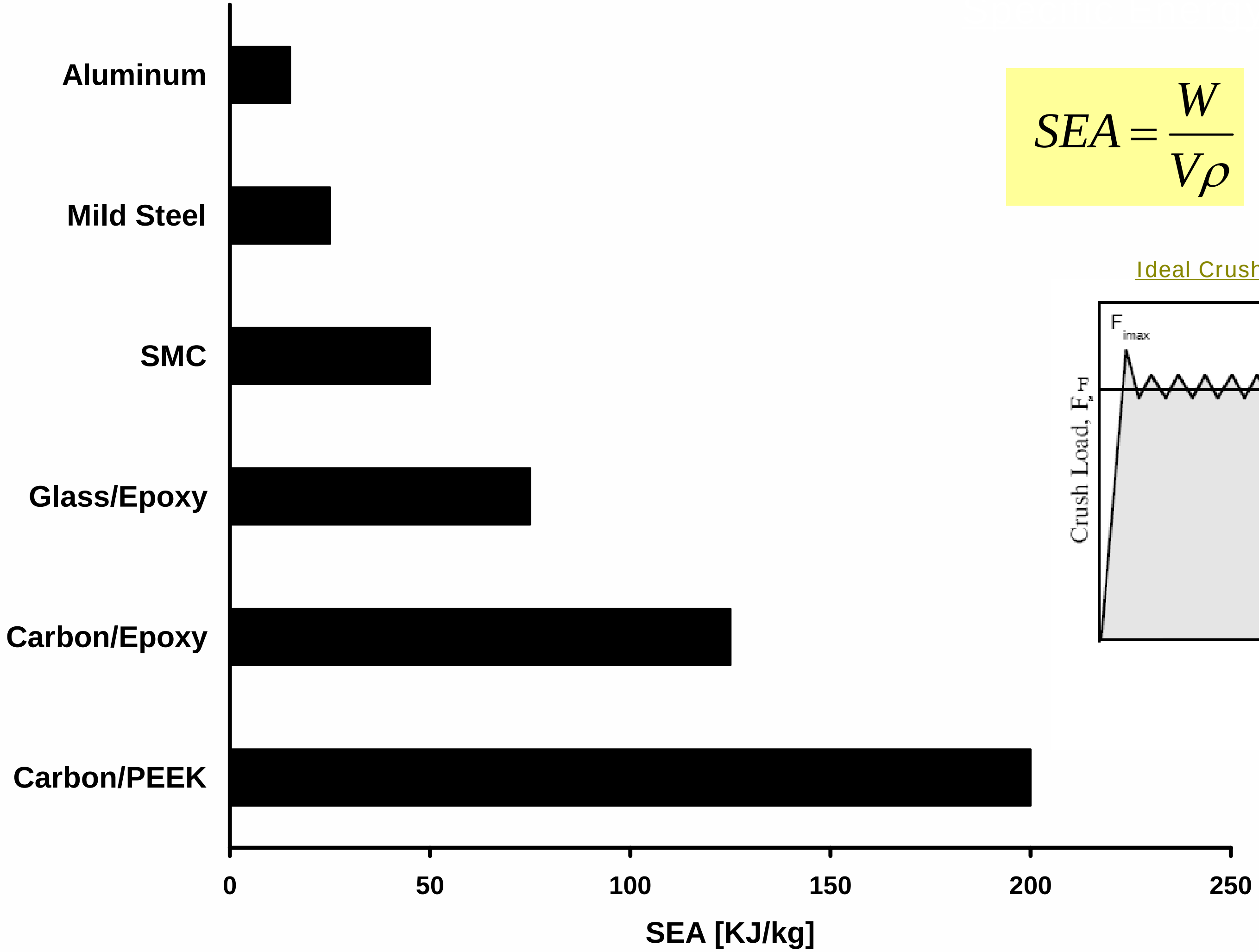
Note the huge impact of power train

Crash Worthiness

Crashworthiness Design Fundamentals

- **Maintain occupant survivable volume or survival space**
- **Restrain occupant (within that space)**
- **Limit occupant deceleration within tolerable levels**
- **Retain "safety-cage" integrity**
- **Minimize "post-crash" hazards (fuel tank leak/projectile etc)**

Safety: Advantage of Composites versus Metal



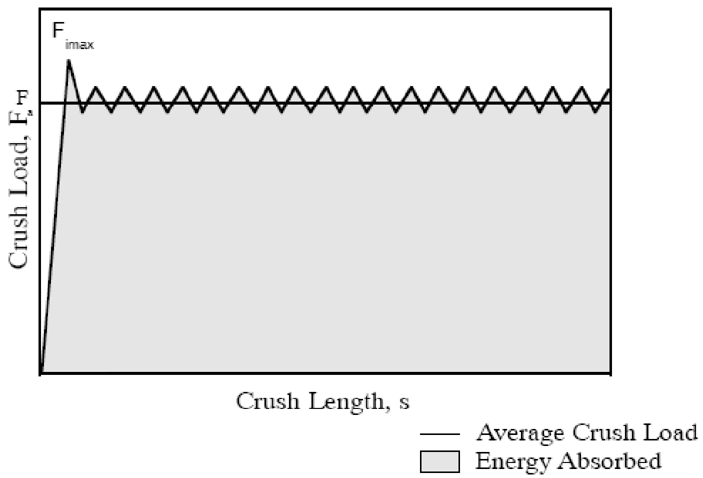
$$SEA = \frac{W}{V\rho}$$

W = Total Energy Absorption = Area under Curve

V = Volume of Crushed Material

ρ = Density

Ideal Crush Load vs. Crush Length Curve



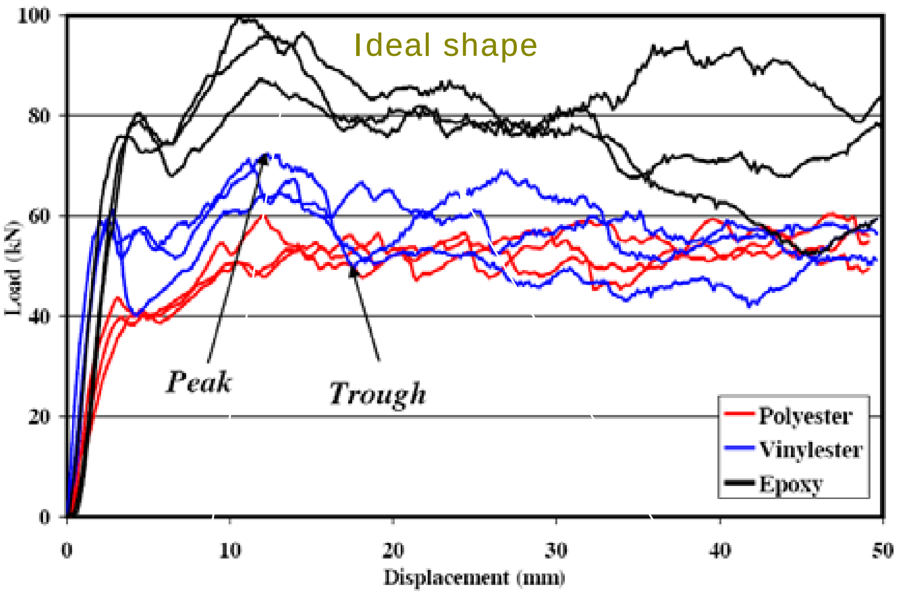
Reference: "Energy Absorption of Structures and Materials," Edited by Lu, G and Yu, T., Woodhead Publication

Different Modes of Energy Absorption

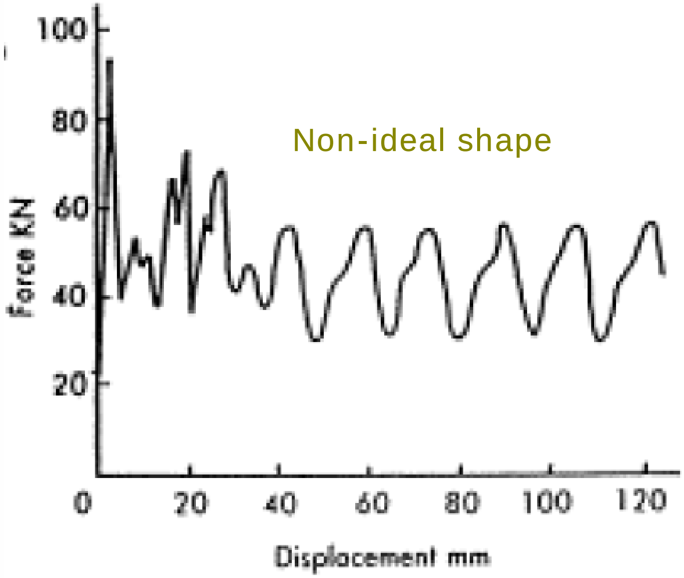
Composite Tubes

(Example below uses Carbon Fiber)

Metal Tube

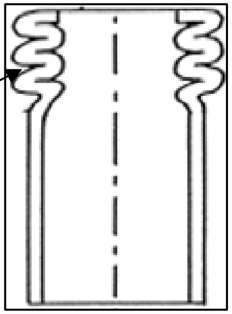


Ideal shape



Non-ideal shape

- Fragmentation
- Splaying



Plastic Buckling

Reference: Bottome, K. J. “The Energy Absorption of Braided and Non-crimp Fiber Composite Material Structures," Ph.D. Dissertation, Nottingham University, London

Effect on Safety

◆ **Reduces damage and injury from accidents**

◆ **Continuous C-fiber Composites are viable candidates for crashworthiness as they exhibit higher energy absorption values (SEA) compared to steel, magnesium and aluminum**

◆ **CFC also best manage deceleration during a frontal crash event to achieve better occupant injury numbers while offering a progressive crush**

◆ **Typically these members are in the form of tubular beams and can be made from glass fiber and carbon fiber for more critical components**

Styling and Part consolidation

Styling and Part consolidation

- CFRP Inner deck lid for Ford GT
  - ➢ consolidation of 4 parts into one due to ability to create complex curvatures
  - ➢ meet safety, weight and cost goals without compromising aesthetics

(ref Sparta composites)

- LGF PP for Polo Front End Carrier
  - ➢ Weight saving
  - ➢ Parts consolidation
  - ➢ Reduced packaging space and more design freedom

Styling and Part consolidation

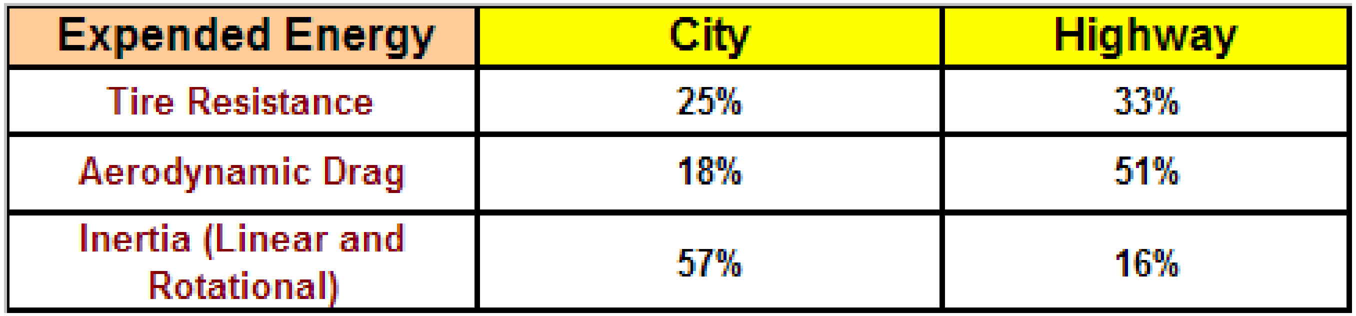
- SMC for GM/Ford Pickup Truck (Truck-box/Tailgate)
  - Multiple parts consolidated
  - Light weight construction
  - Corrosion resistance

- Glass/Epoxy top sleeper
  - Light weight
  - Part consolidation
  - Class A surface

Aerodynamic Design and Fuel Efficiency

Is it Aerodynamic Design?

- Energy losses – City vs. Highway driving

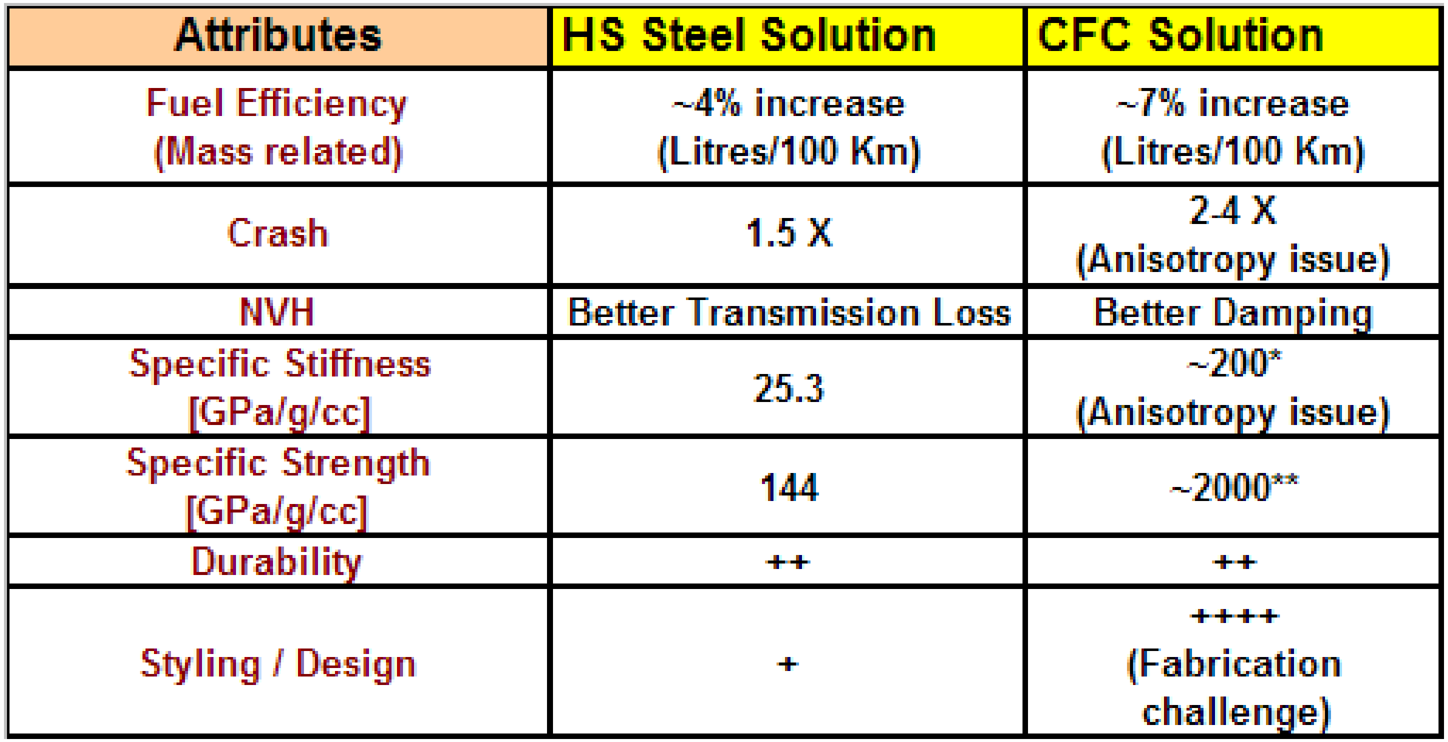


Expended Energy	City	Highway
Tire Resistance	25%	33%
Aerodynamic Drag	18%	51%
Inertia (Linear and Rotational)	57%	16%

- Average drag coefficient (C_d) of modern sedans ~ 0.32 (J from 0.35-0.45 in 70's); Achieving C_d of 0.272 (15% J) would enhance fuel economy (projected)
  - ✓ 0.6 mpg in urban driving (2.8%)
  - ✓ 2.8 mpg in highway driving (8.6%)
  - ✓ 1.1 mpg in combined fuel economy (4.7%)

Every 2% improvement in C_d is expected to enhance fuel economy by 1.4 mpg (0.6%) ..!!

Comparison of HS Steel vs CFC (Auto)



Attributes	HS Steel Solution	CFC Solution
Fuel Efficiency (Mass related)	~4% increase (Litres/100 Km)	~7% increase (Litres/100 Km)
Crash	1.5 X	2.4 X (Anisotropy issue)
NVH	Better Transmission Loss	Better Damping
Specific Stiffness [GPa/g/cc]	25.3	~200* (Anisotropy issue)
Specific Strength [GPa/g/cc]	144	~2000**
Durability	++	++
Styling / Design	+	++++ (Fabrication challenge)

* Calculated based on 50% CFC

** CF specific strength

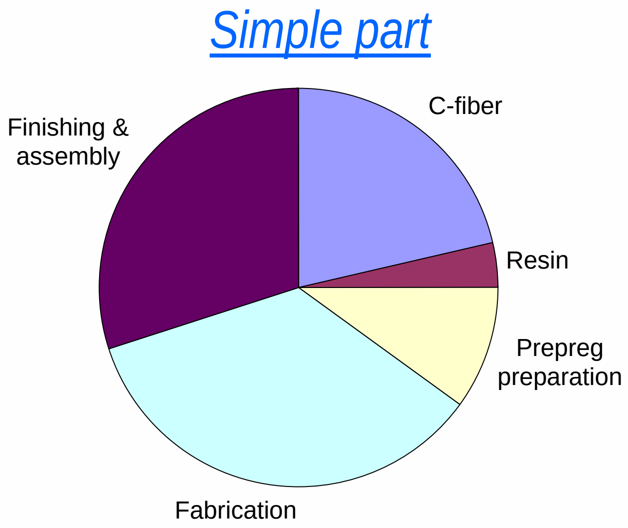
Why Not Composites?

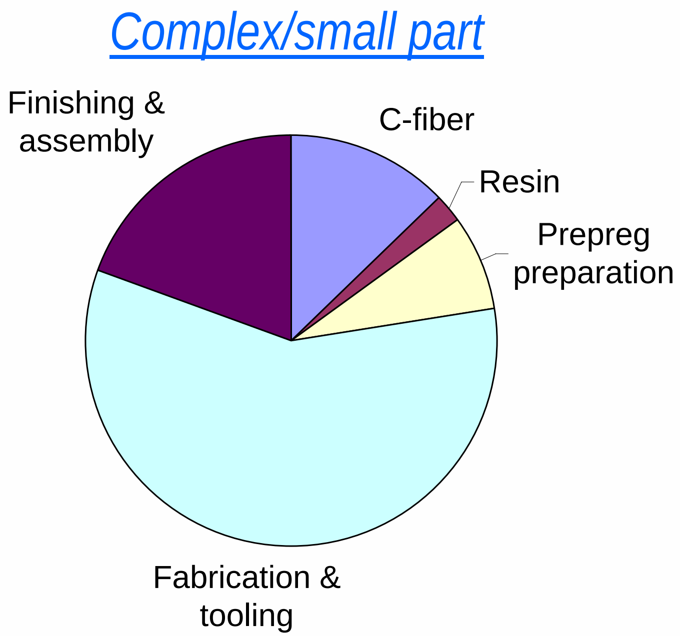
- Is it low cycle time for higher volumes?
- Is it CFC cost?
- Is it general engineering experience?
- Is it adaptability to current metal based assembly lines for high volume cars?

Low cycle time for higher volumes

Typical distribution for part cost

- **The final composite part cost is heavily dependent on fabrication (*e.g. cycle time, automation, reject etc*.) & tooling cost which increases with part complexity and lower part size (RTM, RIM, Pultrusion….)**





Source: SRI Process Economics Report nr.165 A Carbon fiber

Part cost vs. build volume

Performance Comparison of Plastic Composites With Metals for Vertical Body Panel Applications

SAE Technical Paper

Document Number: 1999-01-0848

Date Published: March 1999

Abstract:

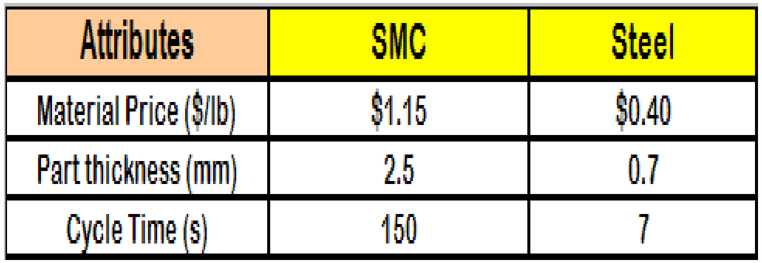
In 1998, approximately 57,000 tonnes of plastic composites were utilized as body panels on cars and trucks in North America. Since plastic body panels have higher material costs but lower tooling costs, they are primarily utilized when build volumes are less than 200,000. For example, at a volume of 100,000 vehicles per year, RIM gives the best cost/performance characteristic for the composite materials and is competitive with steel at this volume.

Part cost vs. build volume – Body Panels

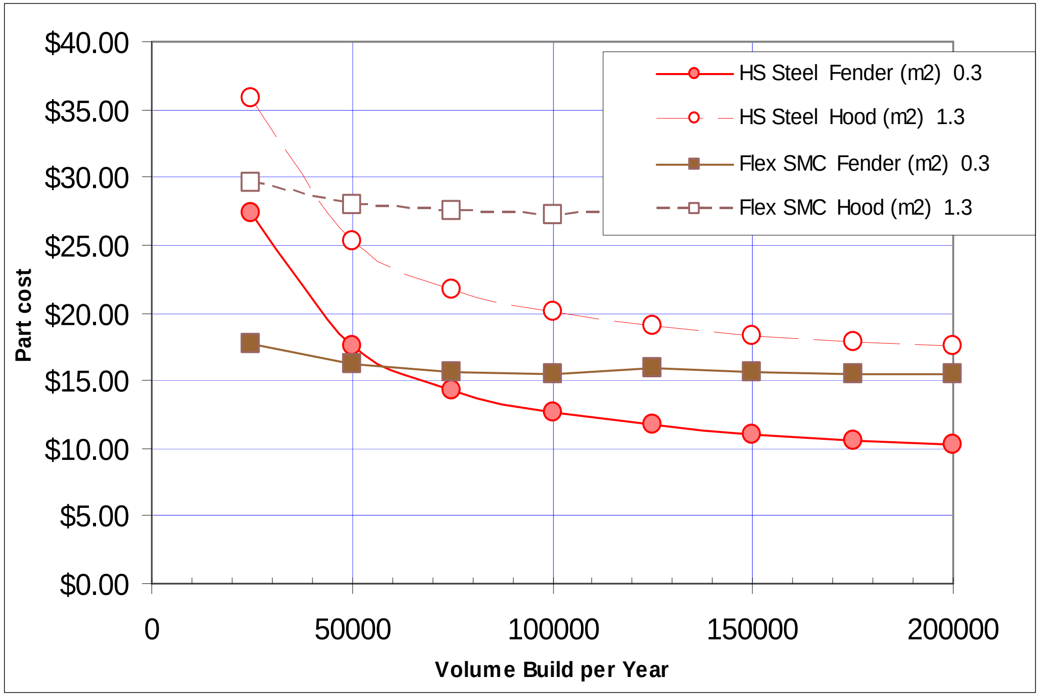
- Body panels are defined as bolt-on exterior panels not integral to the body structure (not including bumper fascia – primarily plastics)
  - Total current plastic body panel market size: 223 MM lbs
  - Total potential market to be created: 525 MM lbs
- Both Vertical and Horizontal body panels share similar requirements to maintain a tough, dimensionally-stable, Class A surface
  - Stiffness requirements of horizontal panels are 3-4x vertical panels (ca. 8000MPa) to provide adequate self-supporting function
- The key to success is
  - a fast-cycle time polymer
  - on-line paint-line temperature capability
  - competitive stiffness-cost balance

Cost Competitivity Analysis

- A detailed cost model was created using a range of surface areas and materials for metal and plastic body panels
- Conclusions

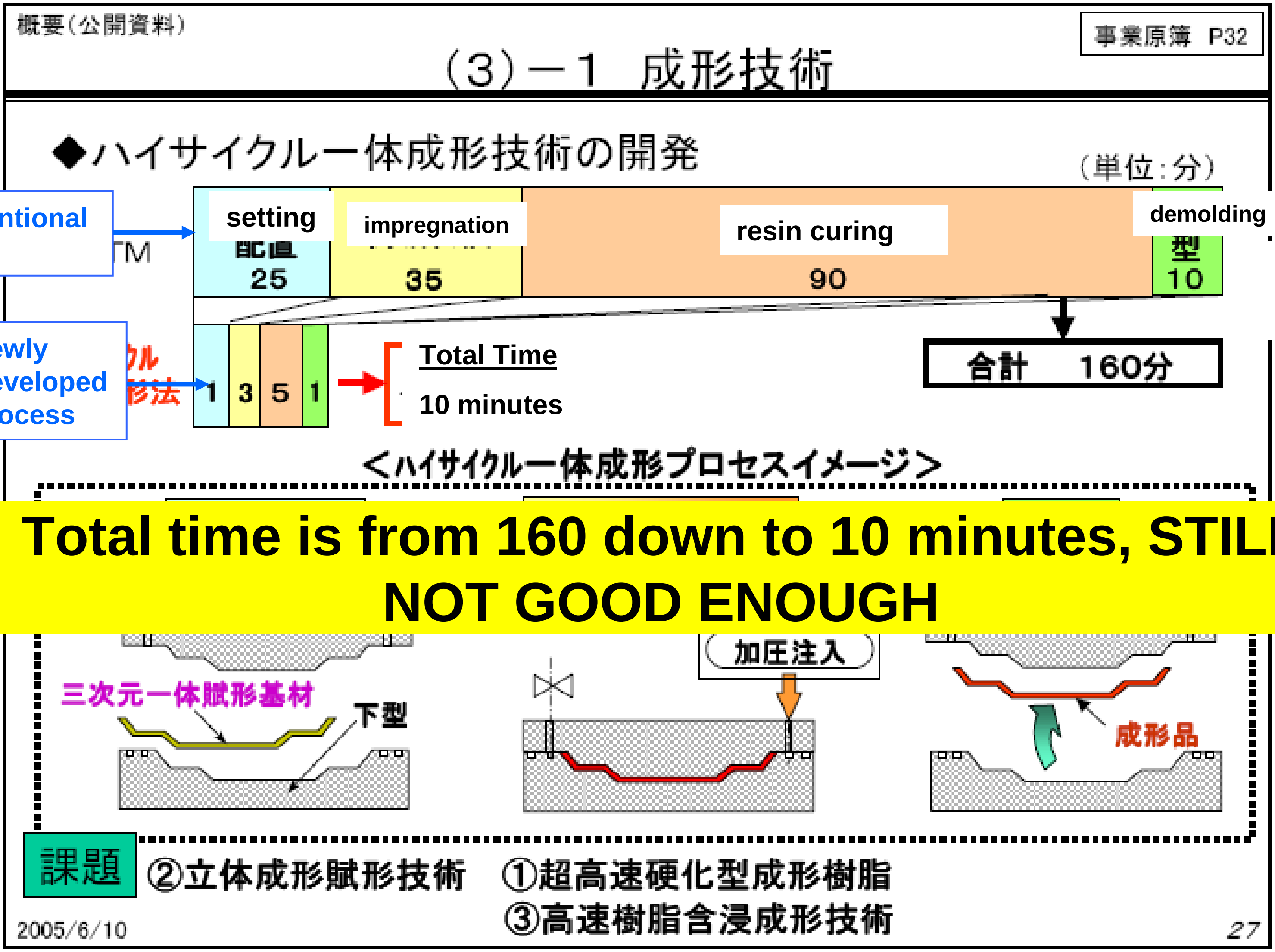


Attributes	SMC	Steel
Material Price ($/lb)	$1.15	$0.40
Part thickness (mm)	2.5	0.7
Cycle Time (s)	150	7



Example of Process Breakthrough Efforts - Nissan

[New process for carbon fiber based door panel production. Still in development.]



概要（公開資料）

事業原簿　P32

（3）－1　成形技術

◆ハイサイクル一体成形技術の開発

（単位：分）

Conventional RTM

	setting	impregnation	resin curing	demolding
TM	配置 25	35	90	型 10
形法	1	3	5	1

Newly Developed Process

合計　160分

Total Time

160 minutes

Total Time

10 minutes

＜ハイサイクル一体成形プロセスイメージ＞

Total time is from 160 down to 10 minutes, STILL NOT GOOD ENOUGH

課題　②立体成形賦形技術　①超高速硬化型成形樹脂
③高速樹脂含浸成形技術

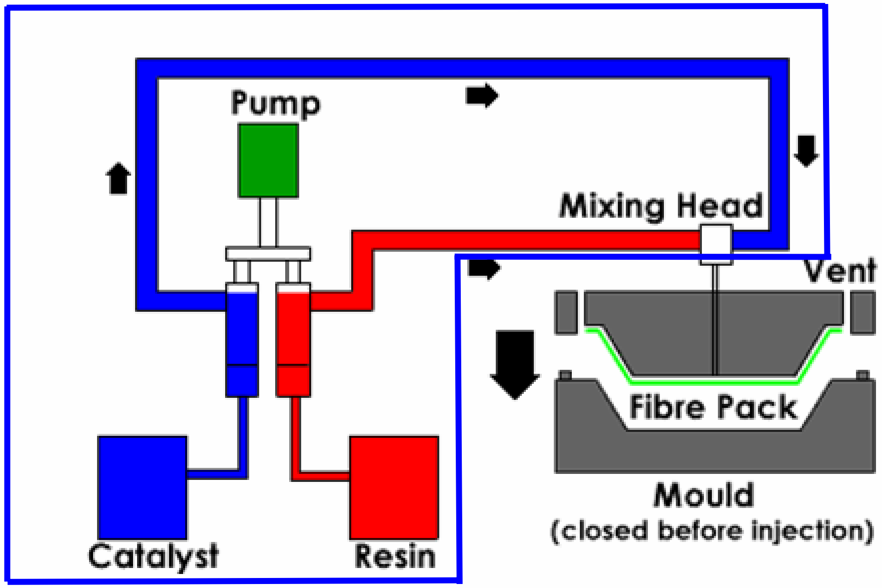
2005/6/10

27

Current Japanese Automotive Consortium (Toray + Nissan + Others)

Recent Developments in Dow Automotive

- **Utilized Dow Rheo-kinetics Modeling to develop reduce cycle time**
  - **Focused on resin delivery strategy**
  - **Currently 2 minute gel time, 5 minute full cure time, Tg>150°C**
  - **No special chemistry (basic Epoxy System)**
  - **Patent Pending.**
  - **Suitable for RTM, RFI and other processes**
- **Need partners that are currently actively pursuing composites**



Carbon Fiber Cost and Supply

Facts on C-fiber

- **A breakthrough in C-fiber cost alone is not an enabler for proliferation, needs breakthrough <u>fabrication technology</u> as well if the world maintains a large car platform approach.**
- **<u>COST</u>: C-fiber has to approach $5 /lb. to be attractive for automotive.** **(<u>References</u>: (1) Sujit Das, ORNL, report written for the Office of Advanced Automotive Technology, 2001 and (2) Willie Jones, Clemson University, Dave Warren, ORNL – interview.**
- **<u>CAPACITY</u>: If every new car used just 5 lbs / 2.25kg of carbon fibre, this would exceed the world's carbon-fibre capacity by 4x!.** **(<u>Reference</u>: David Warren, ORNL at the UK Low Carbon Generation Conference)**

What Vision Could be……..

"Carbon Fiber Composite (CFC) will become the main stream material of construction of ground transportation vehicles in the year 2030"

IF

- **Carbon fiber cost $4-5/lb - Ample supply and steady price**
- **Cars use monocoque design or Integrate multifunctional structures**
- **Fabricators making parts @ 2-4 mins cycle time**
- **Significant investment away from metal based assembly lines**

To reach this vision, strong partnerships between producers, fabricators and OEMs have to take place. Without breakthroughs, CFC will remain a distant second to metals in all ground transportation sectors