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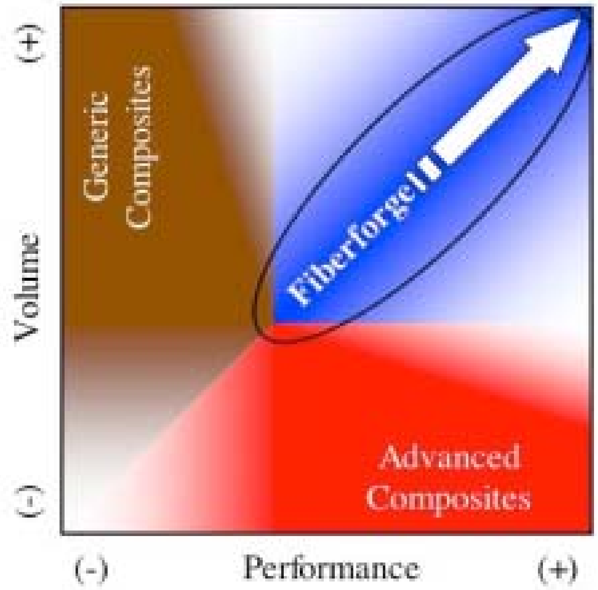
A Novel Approach to Improving Cost-Effective Production of Advanced Composite Structures in High Volume

Presented at the 4th Annual Society of Plastics Engineers Automotive Composites Conference

14 September 2004



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Fiberforge

» ***Our Focus***

> Developing the most cost-effective manufacturing solutions for advanced composite structures produced in high volume

» ***Our Goal***

> Bodies-in-Black™ in high volume

» ***History***

> Founded in 1999

> Initial work focused on lightweight vehicle design

> Since 2002, the Company has focused exclusively on the development and commercialization of its composite manufacturing technology

Numerous hurdles face advanced composites for automotive applications

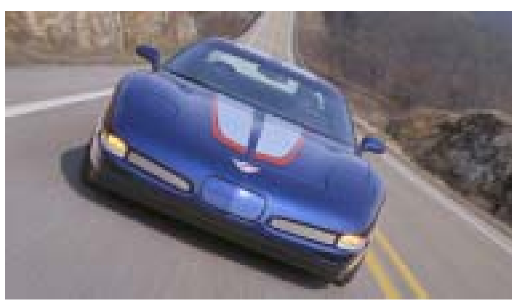
- Raw materials cost
- Volatility of price and availability of carbon fiber
- Availability of proven high-volume capable processing techniques
- Predictive engineering capabilities for processing and failure
- Design know-how and industry familiarity
- Standards
- Etc.

Advanced composites in automobiles

- » Semi-structural applications abound
  - > Advantages of part integration, light weight, system cost savings, design flexibility, improved mechanical performance
- » Currently, advanced composites are used by “innovators” and “early adopters” for niche applications
  - > Superior performance (stiffness, light weight)
  - > High material cost and processing cost
  - > Building familiarity with materials among engineers and customers
- » Industry must build on those successes, expanded niches with new approaches to processing that are designed for higher volumes without sacrificing the performance benefits inherent in the material








What is the Fiberforge Process?

- **Thermoplastic composite sheet forming process that uses "tailored blanks"**
  - **Step 1:** Automated lay-up of tailored blank
  - **Step 2:** Consolidation of tailored blank
  - **Step 3:** Thermoplastic stamping
  - **Step 4:** Trim
- **Targets main cost and performance drivers**
  - **Materials cost**
    - **Raw materials, in-process scrap, efficient use of materials by tailoring the laminate to the load paths in a part**
  - **Manufacturing cost**
    - **High material throughput during creation of tailored blank, short cycle time for final processing, high levels of automation**
  - **Structural performance**
    - **Continuous or long-discontinuous fibers, high fiber volume fraction, tailored orientation**
- **Fiberforge process is flexible**
  - **Many reinforcements, thermoplastic matrices, and even thermoset-based composites could be processed**

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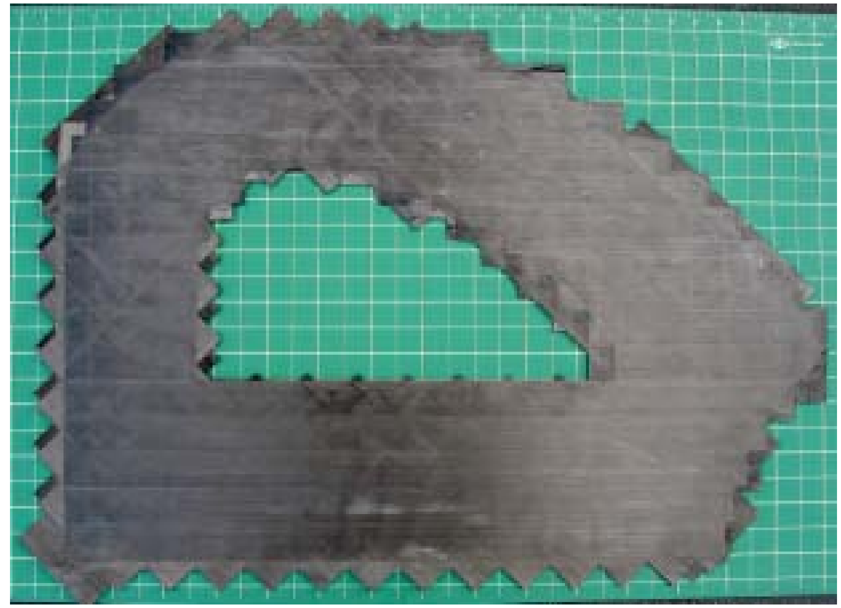
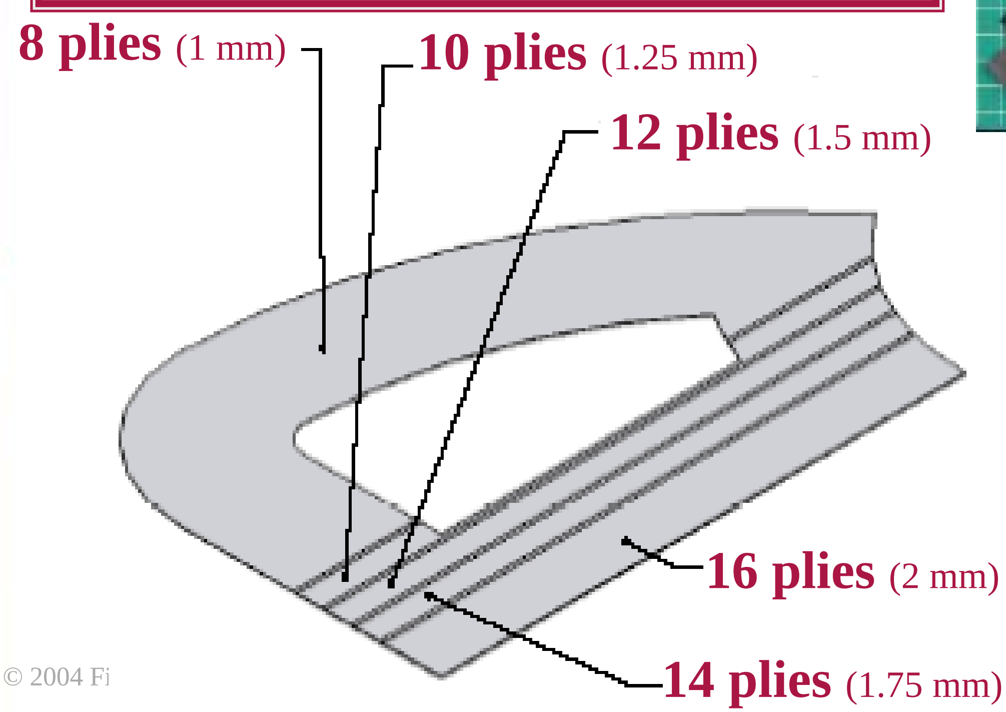
Image sources: C2 Composites, Radius Engineering, Cincinnati Machine

What is a tailored blank?

- Flat, semi-consolidated laminate
- Precise fiber orientation in each ply
- Fiber orientation is tailored to part-specific loading
- Multiple fiber types and volume fractions possible within a part
- Shape tailored to part geometry
- Variable thickness

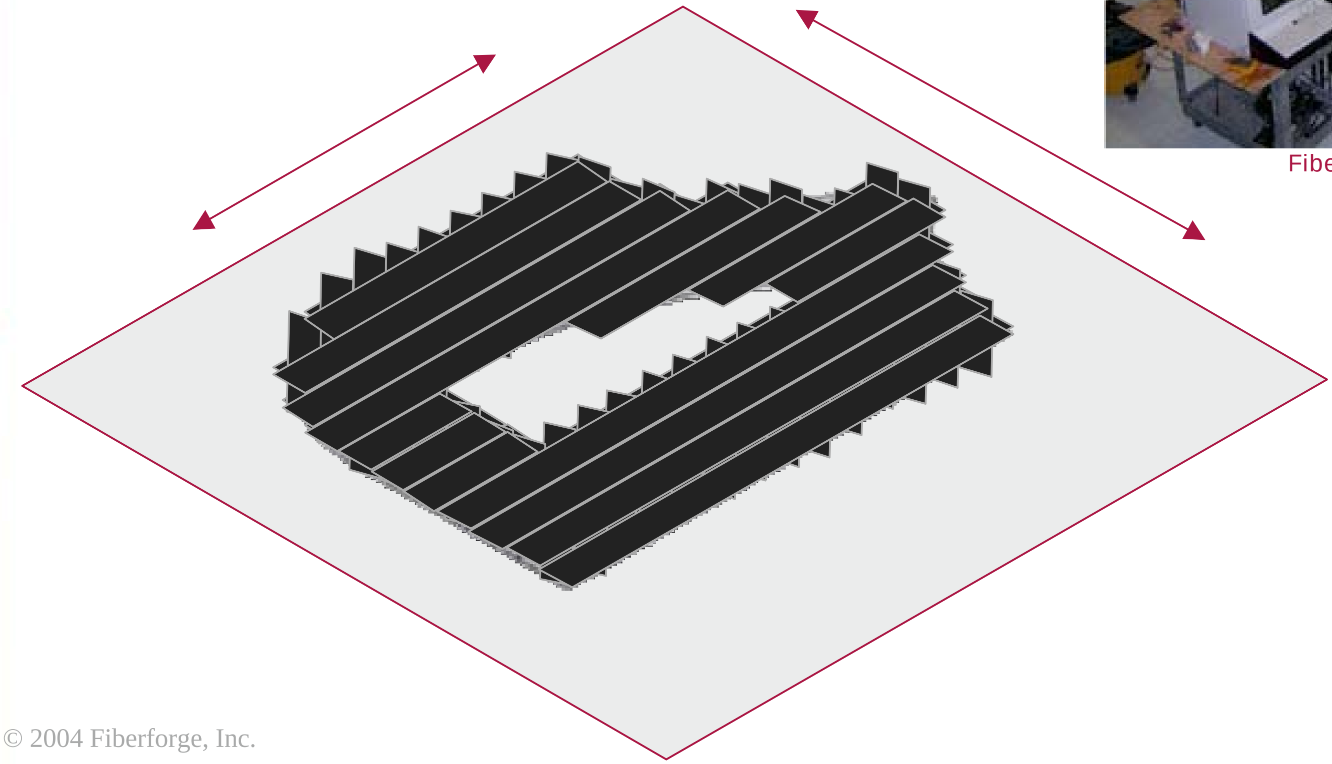




Automated lay-up of a tailored blank

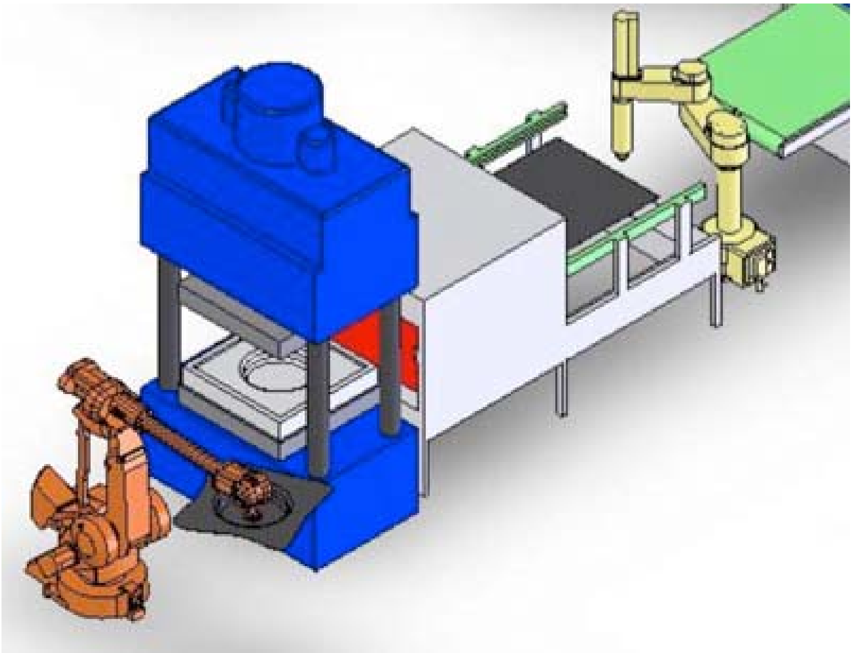
- Starts with raw materials, combining fiber and matrix material in line
- Intermittent lay-up
- Tacks strips of material together
- Rapid material deposition

Fiberforge prototype manufacturing cell



Stamping

- » Heat blank in infrared oven
- » Shuttle into tool and press
- » Close press to form and cool part
- » Less than 90-second cycle time



Fiberforge thermoforming press, pictured

- 1-m x 1-m working area
- 810-mm daylight
- 400-ton pressure
- 100-kW infrared oven, 60-kW tool heating
- Automated blank shuttle system
- Air-water mist cooling

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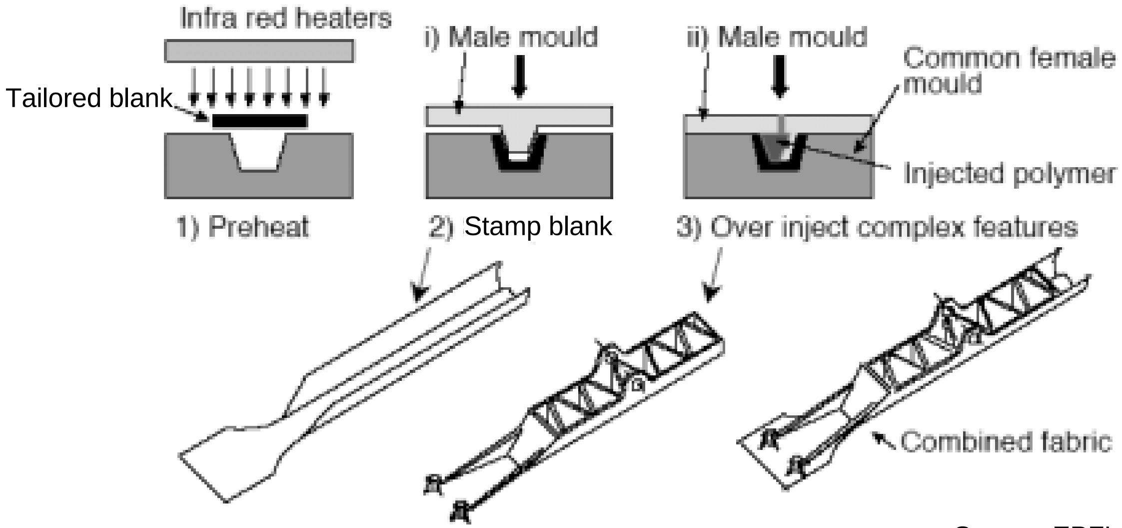
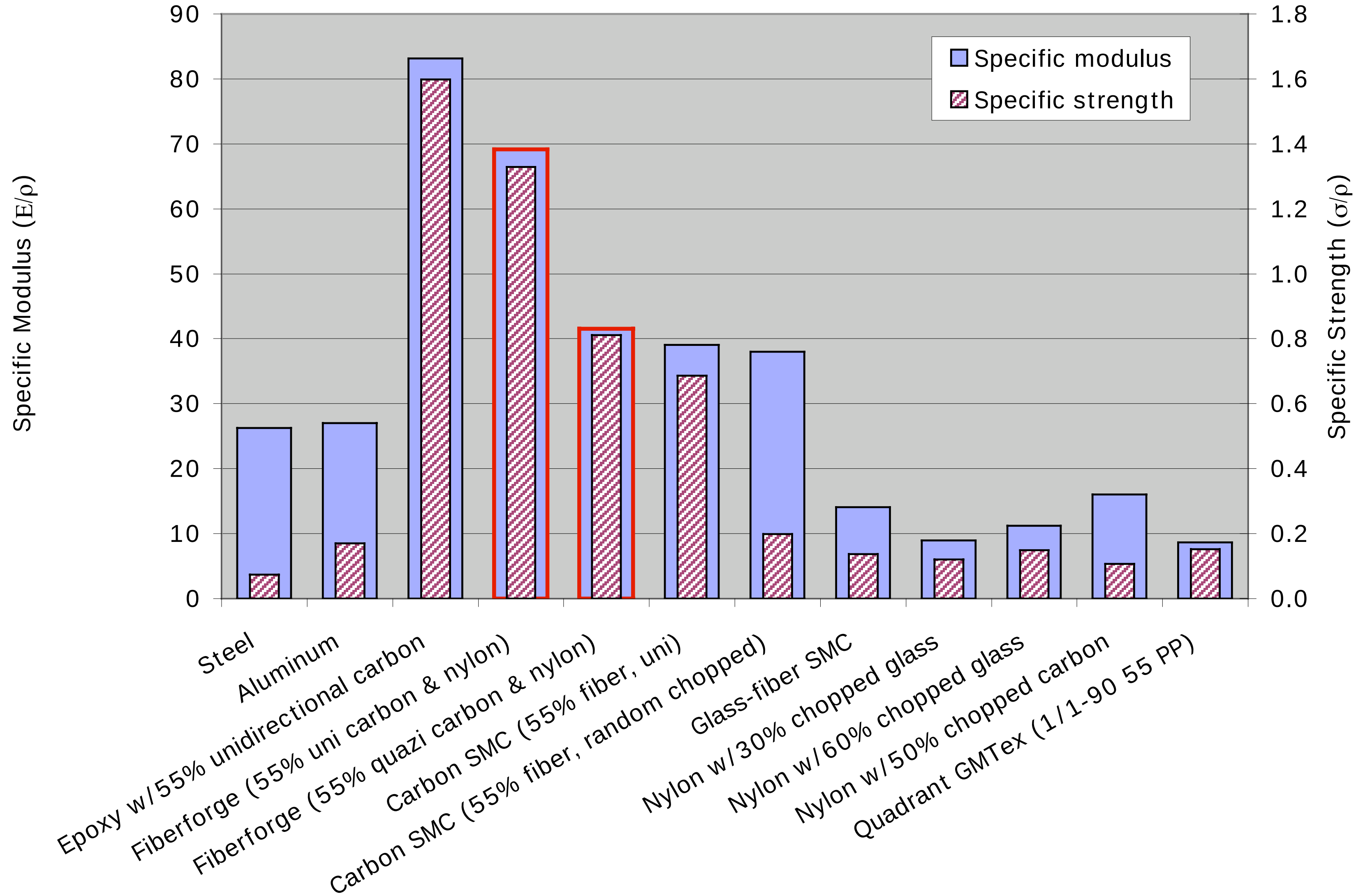
Many process variants are possible

- Using various starting materials
- High-volume and low-volume equipment configurations of the tailored blank fabrication equipment
- Hybrid manufacturing processes (illustrated)



Source: EPFL

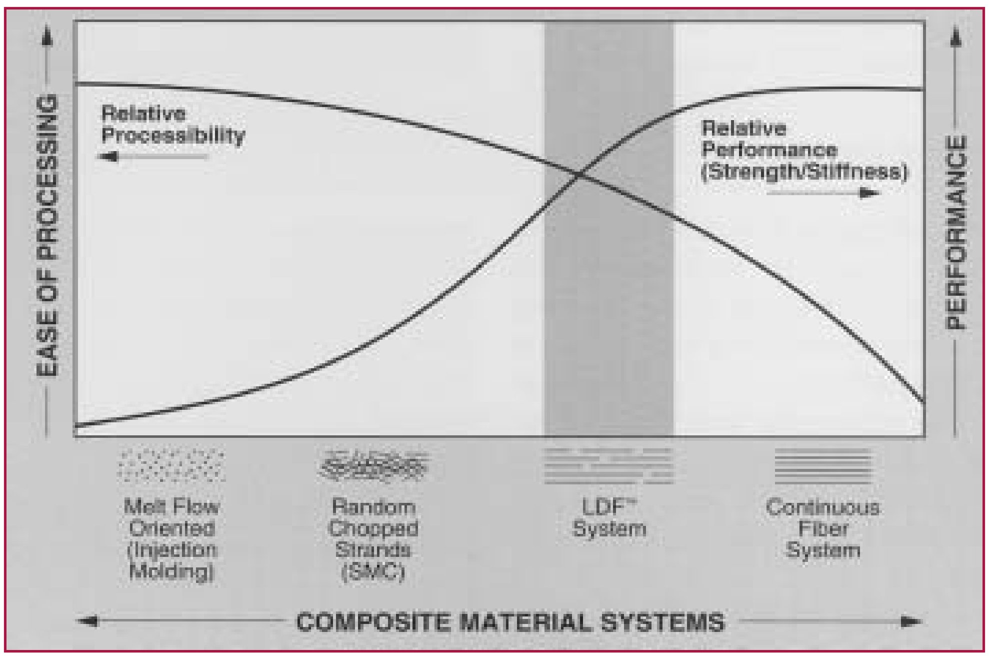
Performance

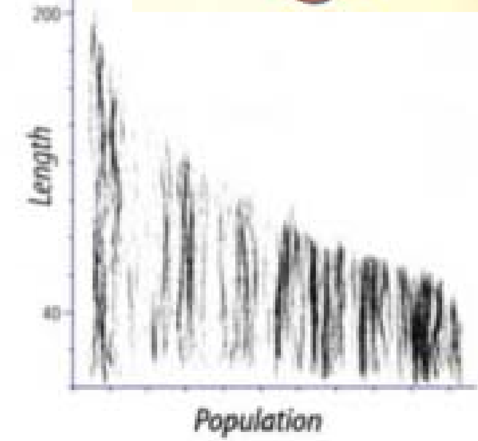


Starting materials: fibers

» Carbon, glass, or other fibers: large-tow fiber possible

- > Continuous
- > Long-discontinuous fiber



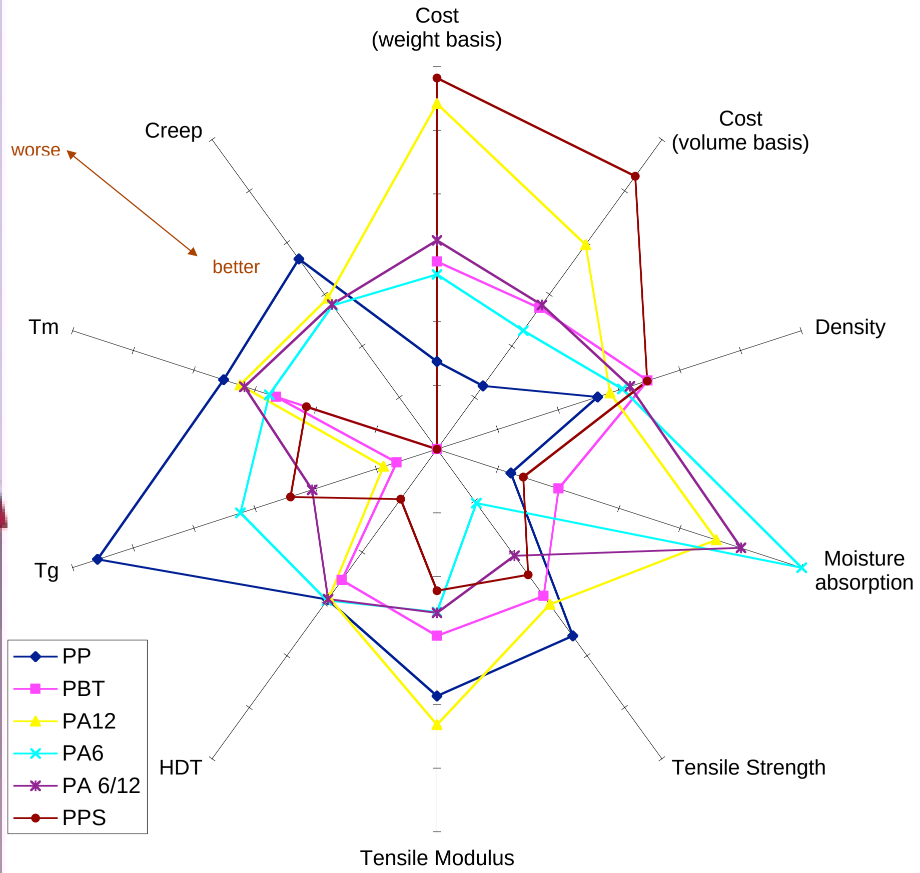


Starting materials: matrix

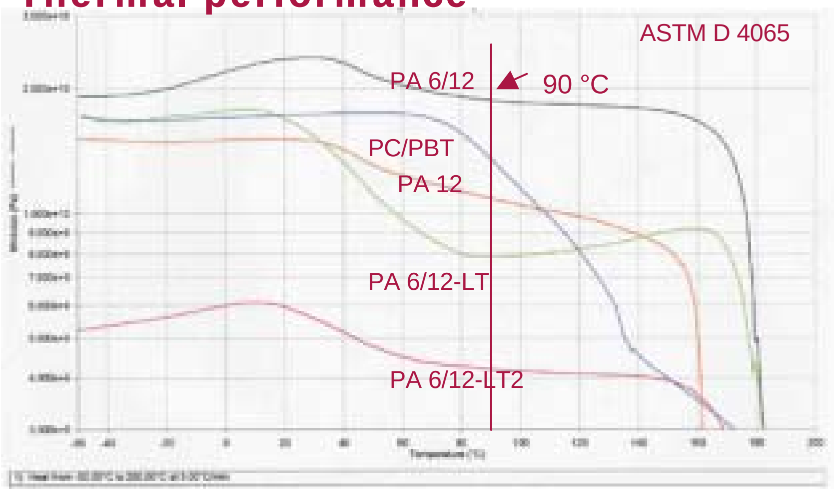
» Many factors to consider when choosing matrix

> Fiberforge baseline materials are grades of polyamide

Multi-criteria comparison

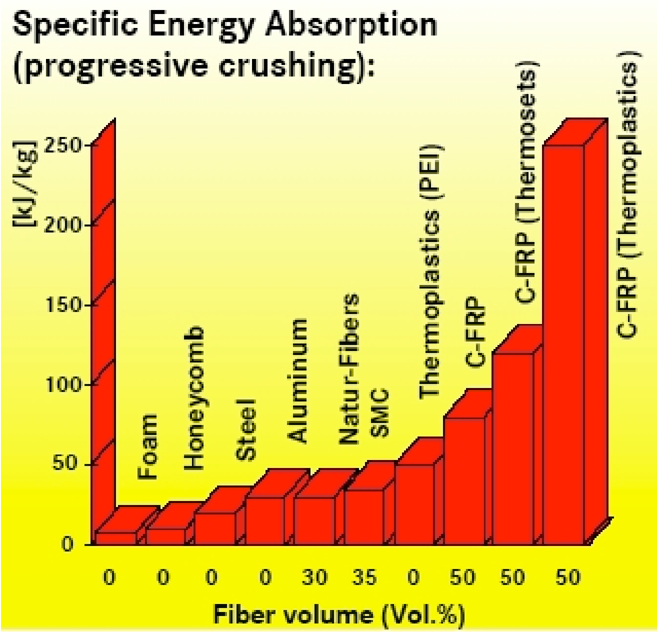


Thermal performance



Benefits of thermoplastics

- » Rapid processing
  - > < 1-min cycle time potential
  - > Non-reactive during part processing
- » Crash energy absorption
  - > > 2x specific energy absorption compared with thermosets
- » More easily recyclable
  - > LFRT feedstock



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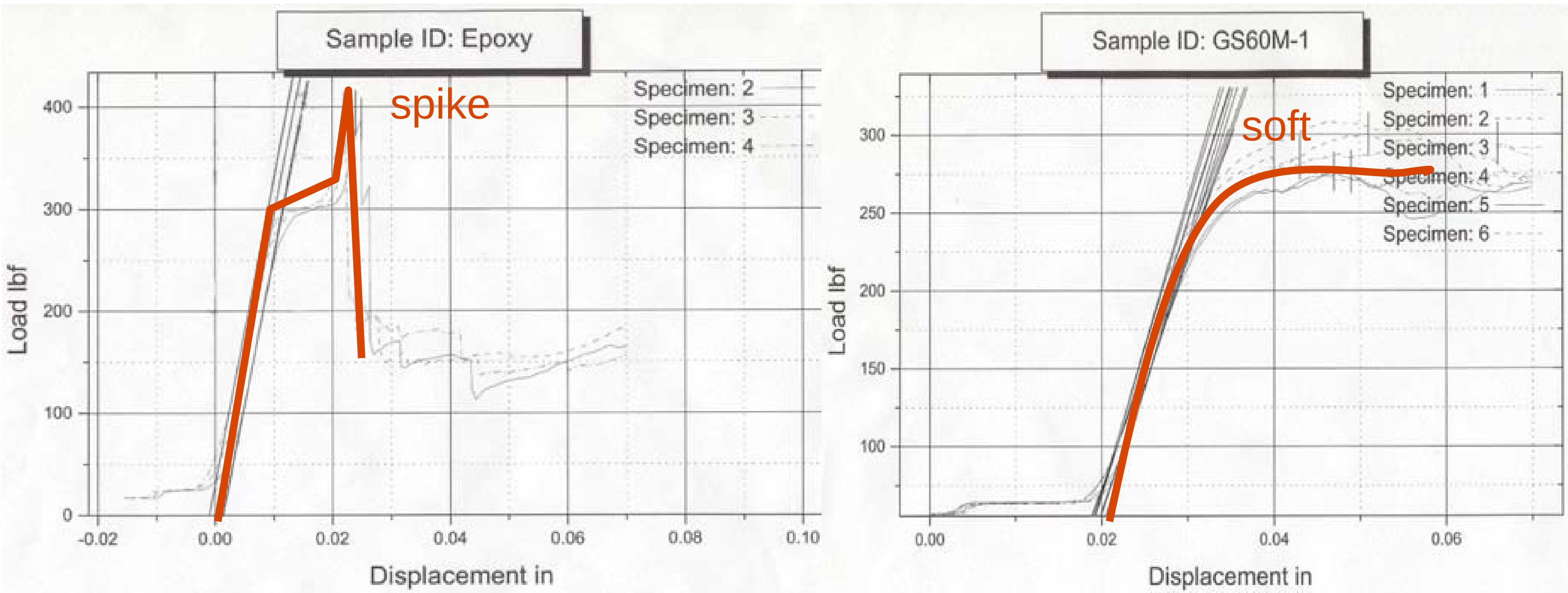
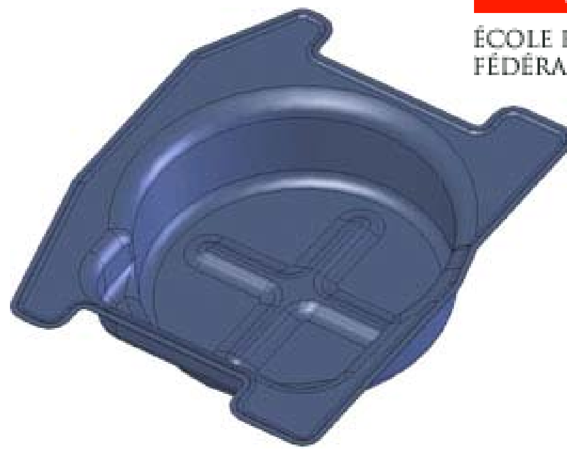
“Graceful” failure of thermoplastic composites



Application case study: Spare wheel well

- Collaborative investigation with Dr. Martyn Wakeman at École Polytechnique Fédérale de Lausane
- Comparison of part cost with several thermoplastic composite starting materials
  - Fiberforge tailored blank (carbon fiber & glass fiber)
  - Thermoplastic prepreg sheet (carbon fiber & glass fiber)
  - Twintex™
  - GMTex™
- Main cost drivers investigated
  - Materials, equipment, labor, facilities cost
  - In-process scrap
  - Carbon fiber vs. glass fiber
  - Tailored blank fabrication speed
  - Dedicated vs. utilized manufacturing
  - Production volume
- Factors not considered in this analysis
  - Optimization of tailored blank shape
  - Structural optimization and refinement of laminate architecture
  - Individualized weight savings based on product requirements

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



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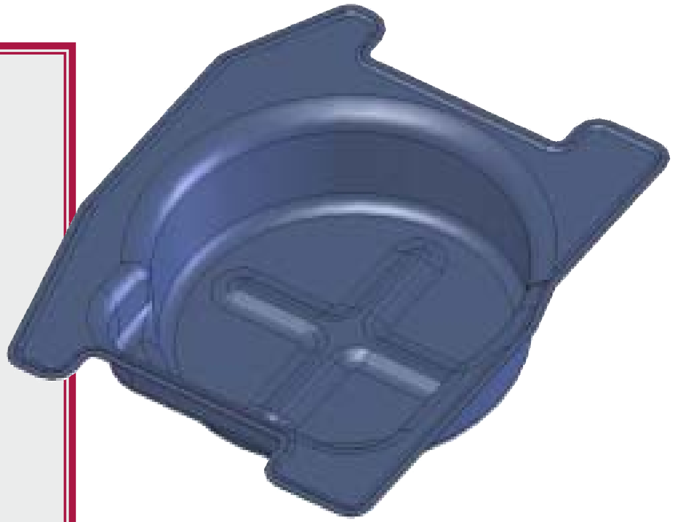
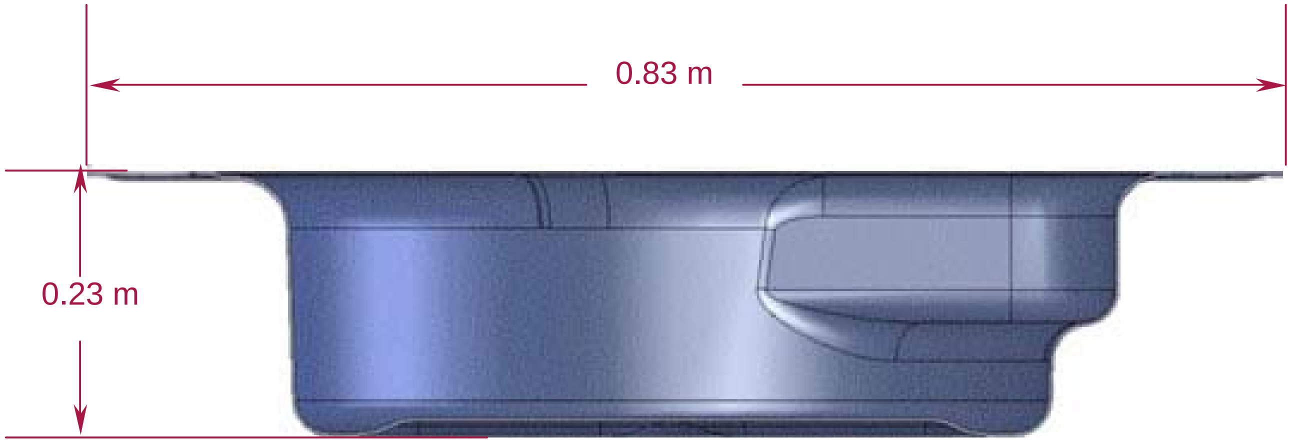
Baseline assumptions

- General
  - Parts produced annually: 20,000, 40,000, and 60,000 parts per year
  - Five years of production, 1–3 shifts considered
  - Indirect to direct labor ratio 60%
  - Interest rate on capital: 7.5%
  - Compound reject rate: 2%
- Material prices
  - Carbon fiber: $17.25/kg ($7.83/lb)
  - Glass fiber: $1.90/kg ($0.86/lb)
  - Nylon matrix: $3.52/kg ($1.60/lb)

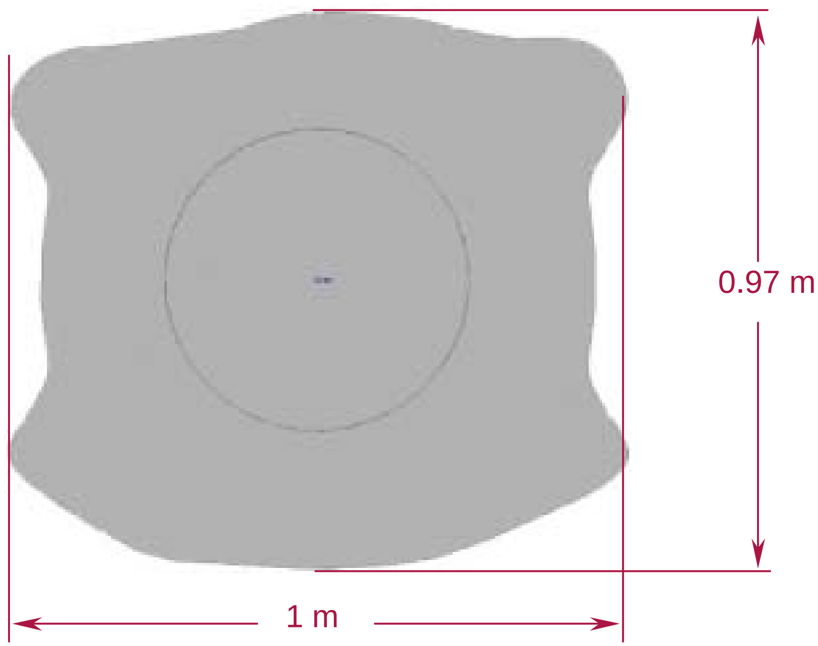
Spare wheel well design

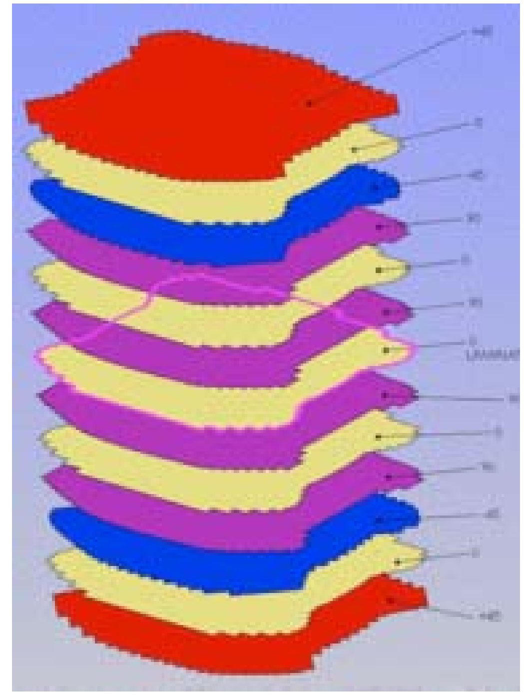
- » Part characteristics & assumptions
  - > 2.5 mm thick
  - > 3-kg mass with carbon fiber, 4-kg mass with glass fiber
  - > Quasi-isotropic lay-up
  - > 50% fiber volume fraction
  - > Polyamide matrix
- » Baseline mass savings relative to steel
  - > 50% mass savings for carbon-fiber parts
  - > 35% mass savings for glass-fiber parts
- » Producible with in-house production equipment

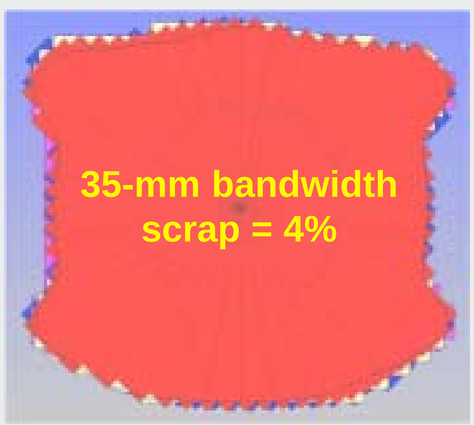




Tailored blank design







Plant layout for Fiberforge process

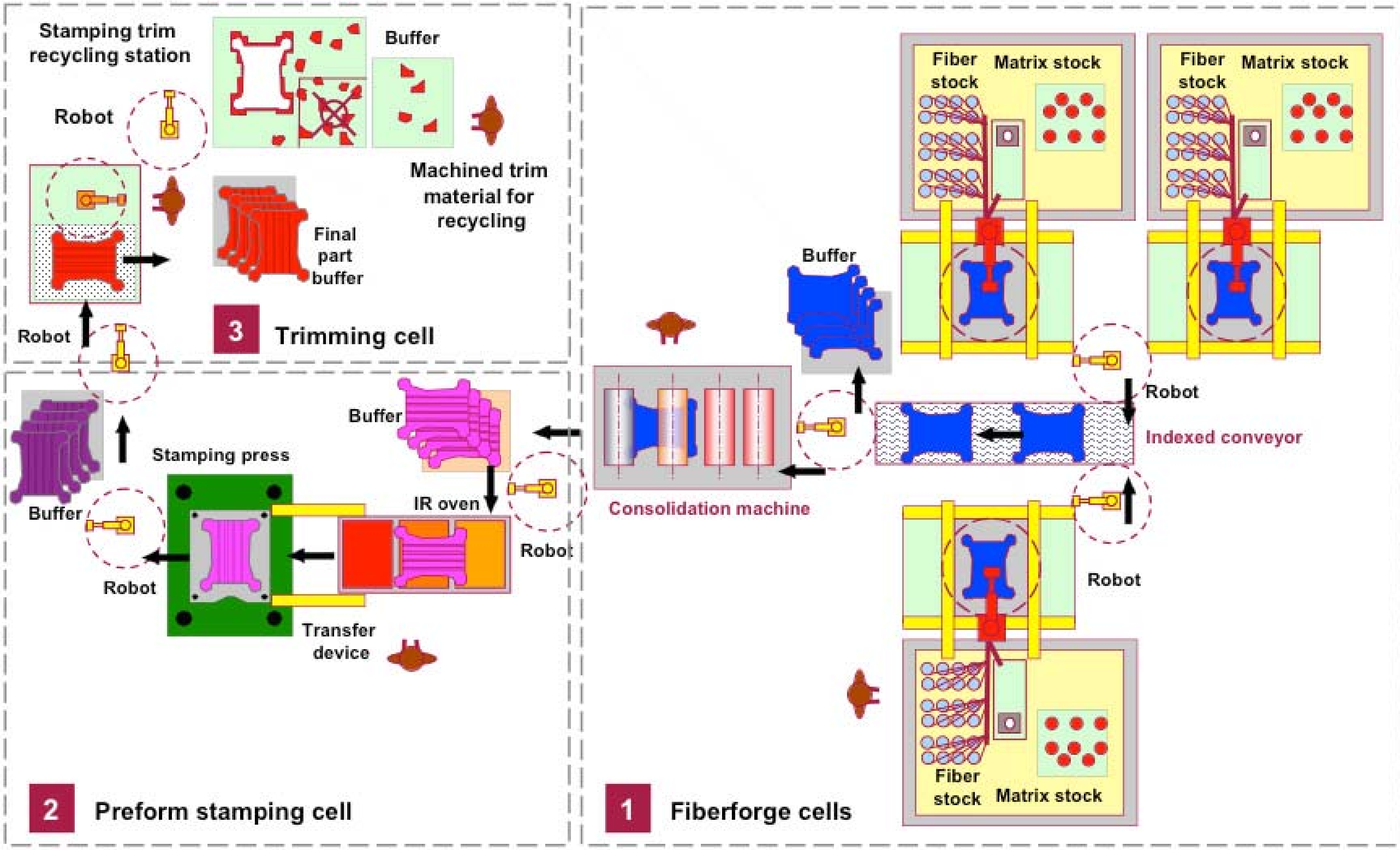
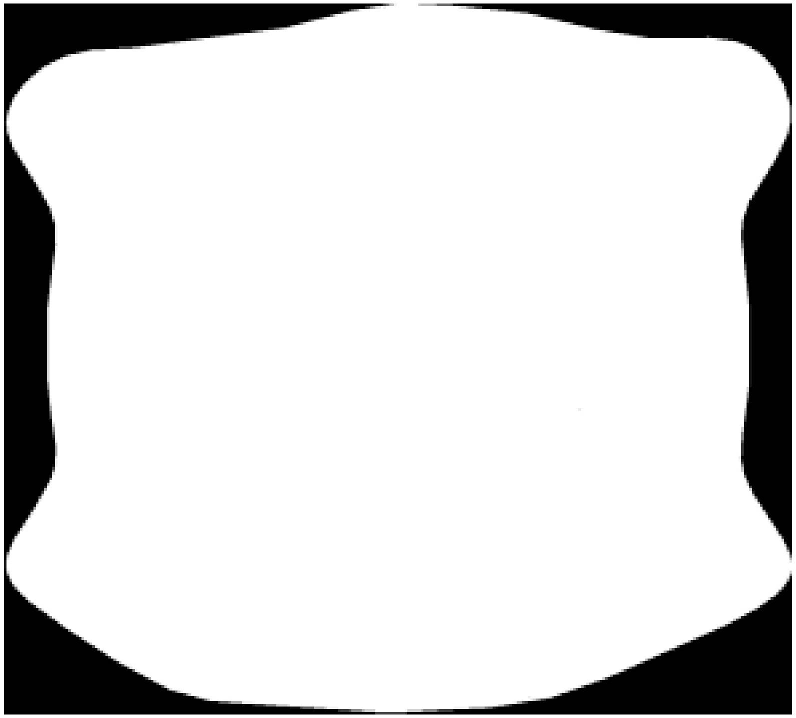
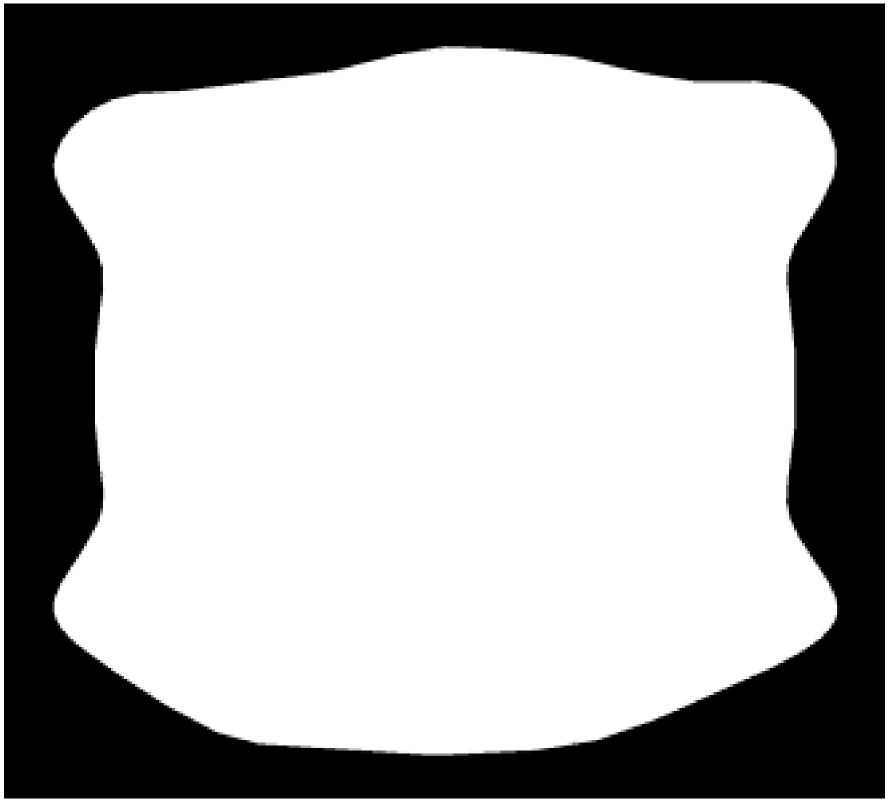


Image Source: EPFL

Scrap for preimpregnated sheet

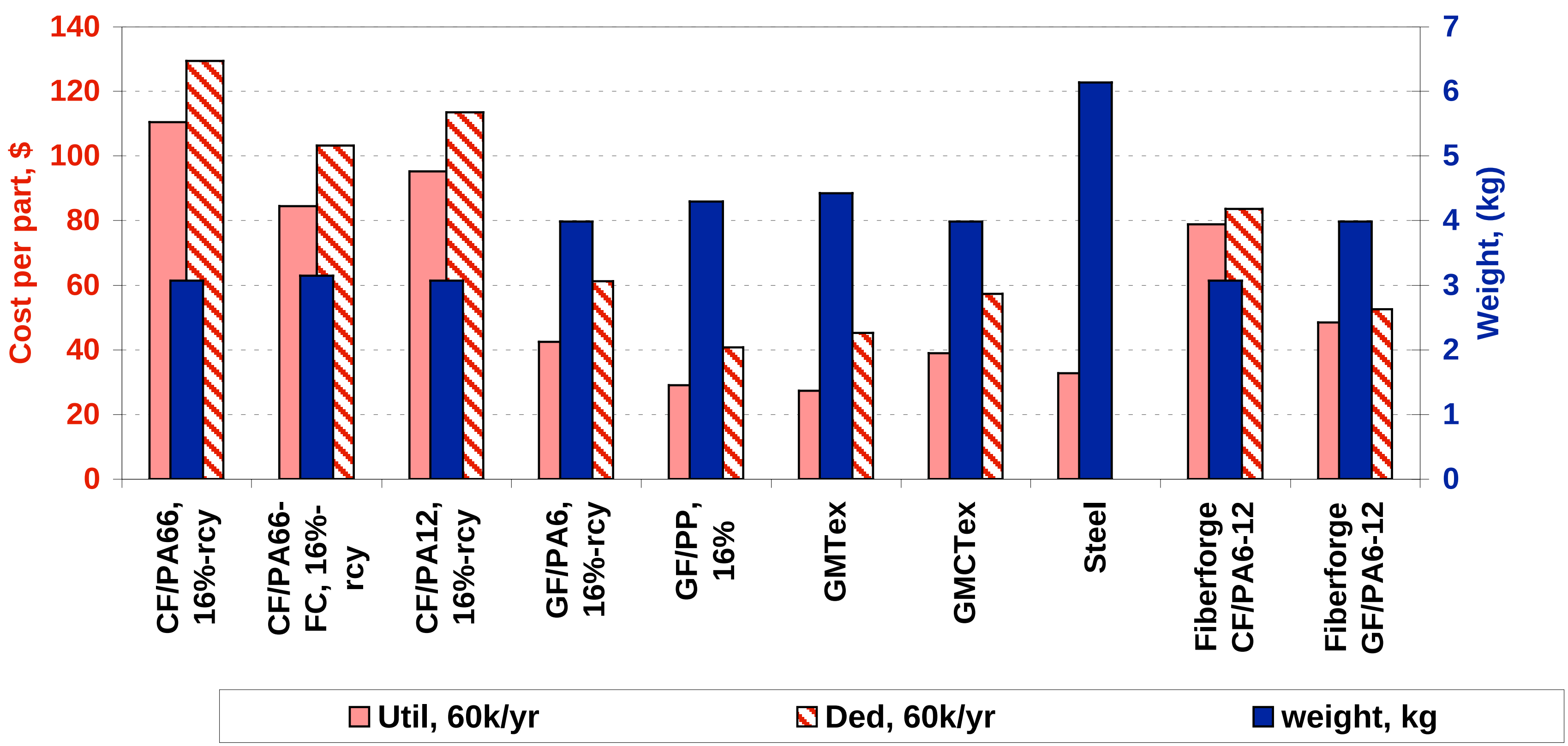


Smallest rectilinear surface—scrap = 16%



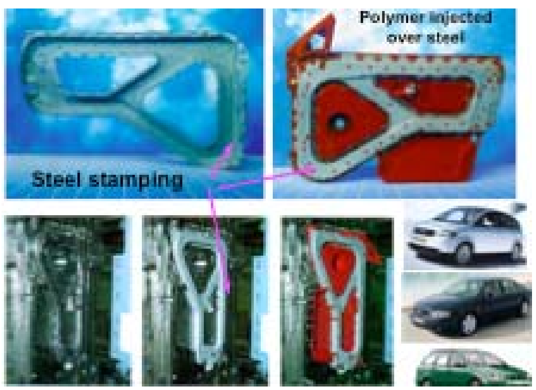
Perimeter blank holder scrap = 33%

Cost summary

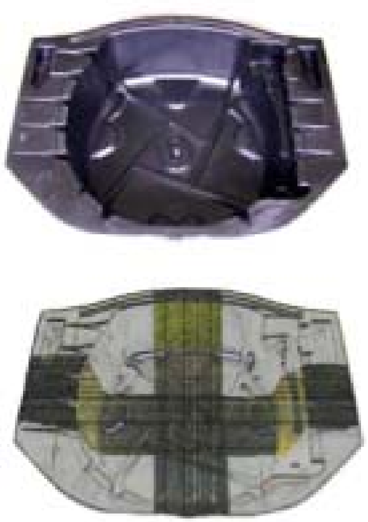


Next steps in cost analysis

» Investigate overall process economics relative to other processing techniques and materials for specific parts
  > Three parts to be chosen that bracket processing potential (hybrid molding, SMC, GMT, sheet thermoforming, steel stamping, aluminum stamping)



Hybrid molding



Oriented glass-fiber composite

Primary structure

Conclusion

- Tailored blanks are cost-competitive with similar starting materials
- Opportunity to further reduce cost by optimizing the fiber lay-up
- Tailored blank technology offers advantages to both glass-fiber and carbon-fiber composites
- Hybrid molding promising; tailored blanks could play a strong role
- Materials cost dominates, but significant opportunities for further cost reduction in processing techniques

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