Integrated Engineering Development Process for lighter, stronger and more cost-effective Composites

Composites, World Materials Forum

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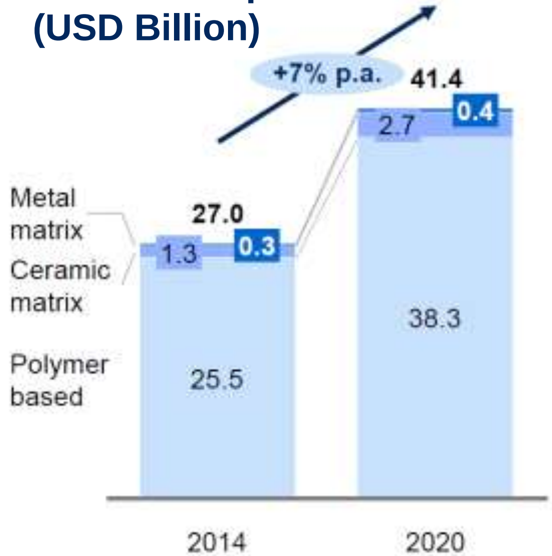
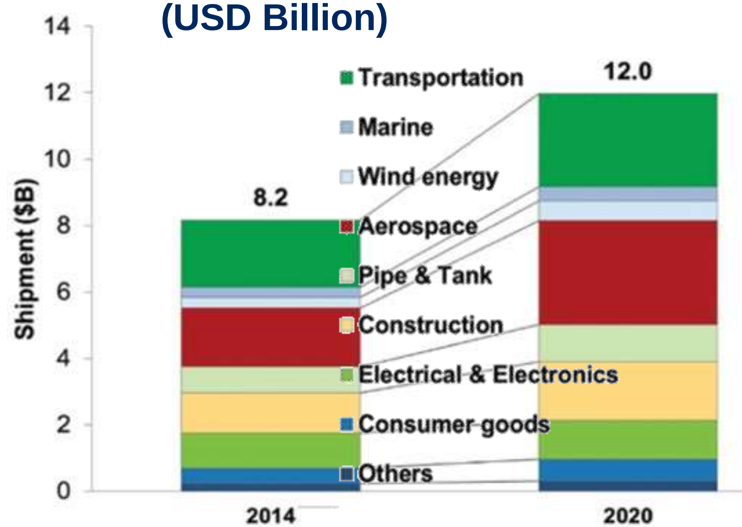
Forecast Composite Automotive (will it happen ?)

❑ **Global composite market (USD Billion)**



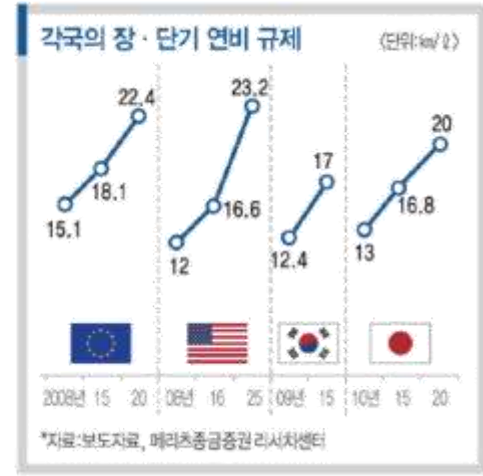
Based on press releases announcing publication of reports from Markets and Markets, Transparency Market Research, Lucintel, McKinsey & Company

❑ **USA Composites Market (USD Billion)**



Lucintel(from Composites Manufacturing Jan/Feb 2015)

❑ **Fuel Regulation, Km/liter**

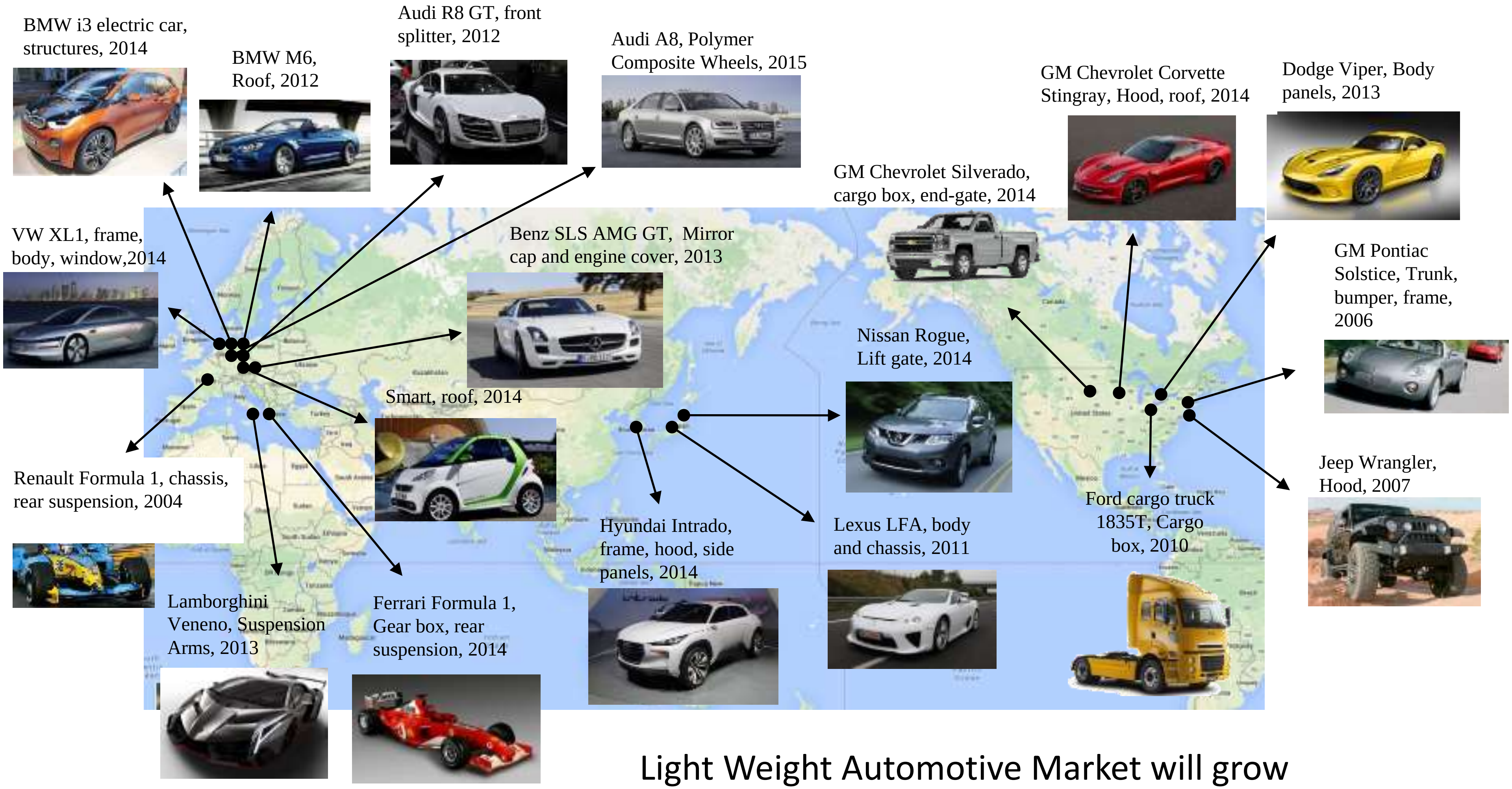


- Save 5% fuel for each 10 % mass saving.

❑ **Aerospace composite industry** made quantum jump when **Boeing 787 and Airbus 380 adopt composites in 2009**; 55% of total mass (was less than 5%), saved 20~25% fuel

❑ **The same will happed to Automotive Composite industry, successfully…**

Light Weight Automotive Industry is growing …



Light Weight Automotive Market will grow more with Electric Vehicle.

Integrated Engineering Development Process (IEDP)

❑ Materials

TS and TS;
Glass, Carbon & Aramid;
Material properties;
Material cost, processibility

- Fibers (carbon, glass, aramid)

- Thermoset & Thermoplastics

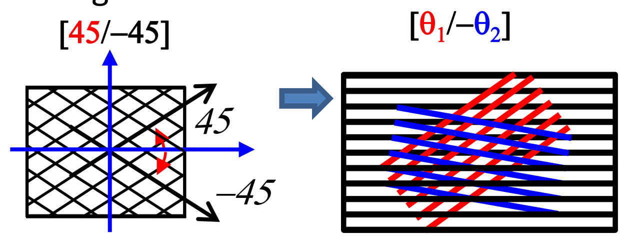
- Non-Crimp or woven Fabrics

- resin pre-preg products & Injection-molding compounds

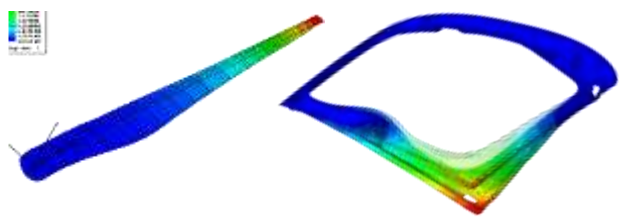
❑ DESIGN

Design for easy process;
Optimal Fiber direction;
Optimal performance and process

- Design Innovation



- Design from Structure Simulation
  - Stiffness, strength, buckling, vibration, fatigue



- Manufacturing Process Simulation

❑ Manufacturing Process

Hybrid Process for cost-effective (high cycle rate) process and better mechanical performance

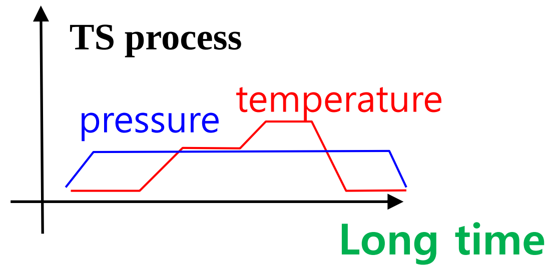
- Mold and Tool Selection

- Manufacturing Process
  - Compression
  - Injection
  - RTM,
  - RIM,
  - C-RTM,
  - HP-RTM,
  - T-RTM

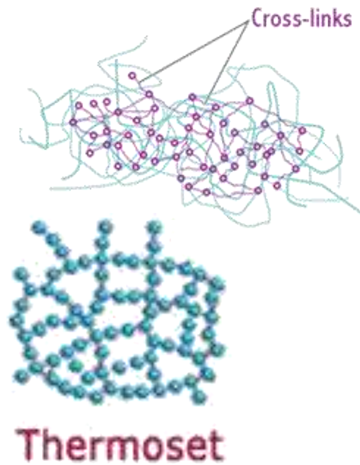
Thermoset vs Thermoplastic : Process

○ Thermoset

- Strong to environmental Heat and Wet
- Low pressure but takes longer process
- Weak to Impact
- No recycling
- Epoxy, PU, PE, VE, …

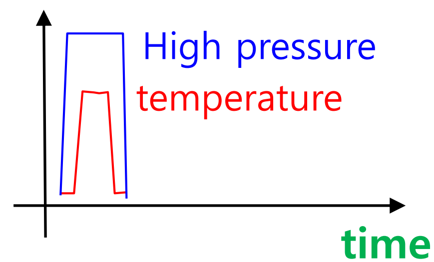


Low temperature,
Low pressure,
Longer cycle time

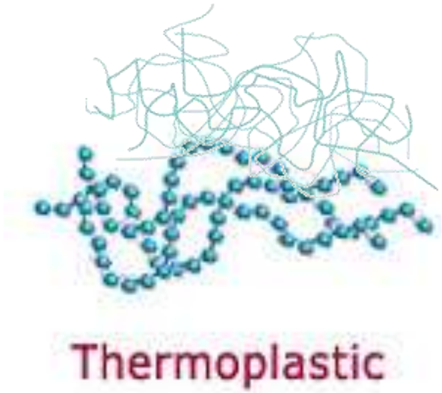


○ Thermoplastic

- Weak to environmental Heat and Wet.
- High pressure but short process
- Strong to impact.
- Recycling.
- PA, PP, PC, …



High temperature,
High Pressure,
Short cycle time

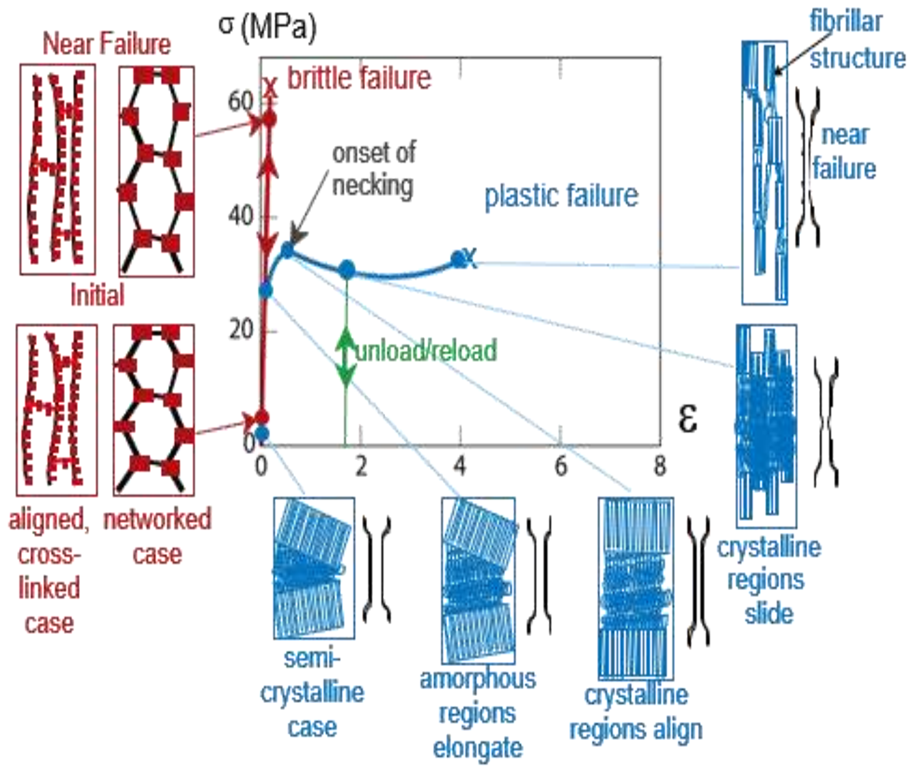


➢ New Process has been developed to shorten the process cycles for TS and TP composites.

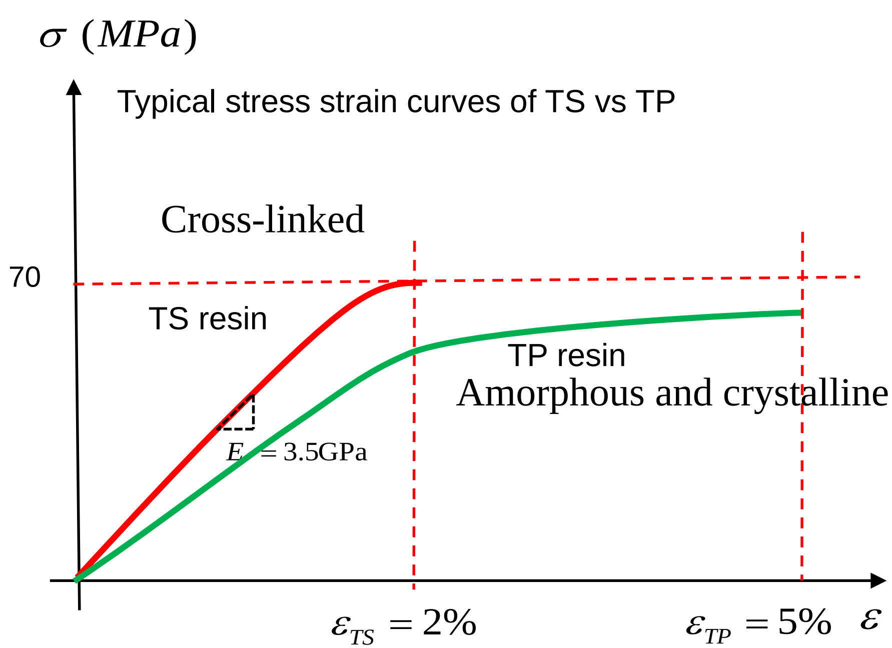
Thermoset (TS) vs Thermoplastic (TP): Mechanical Properties

➢ The failure strains of Thermoset (TS) vs Thermoplastic (TP) resin: about 2% vs **5%**.

- Thermosets : cross linked
- Thermoplastics : amorphous & Crystalline

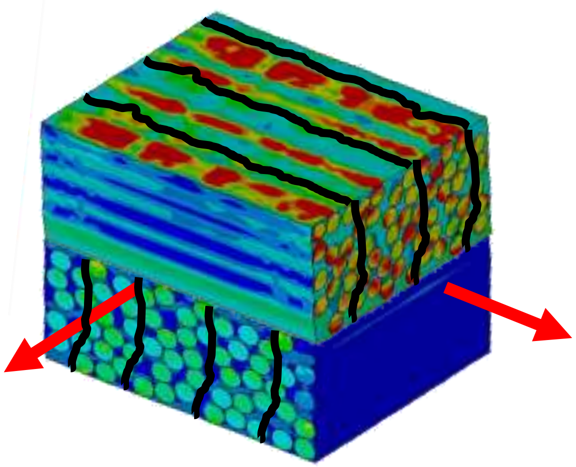


In the fiber reinforced composites, **the failure strains** of resins play more important role than the strength. The fibers and resin deform together..

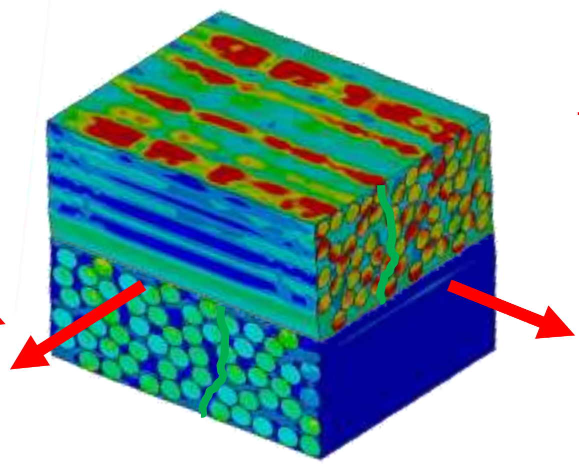


Failure of TS vs TP Composites under Multi-axial loads

- Under Multi-axial Loads, 90 deg ply of TS composites can easily crack.
- Higher failure strain of 90 deg ply of TP composites may delay crack initiation.
- Higher failure strain is more desired feature than higher strength.

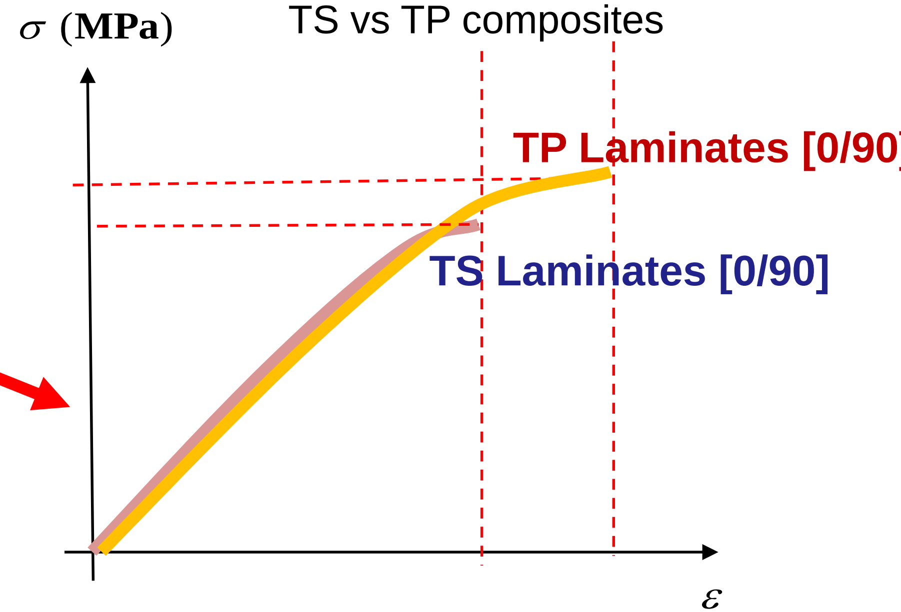


- TS Composites



- TP Composites

Stress strain curves of TS vs TP composites



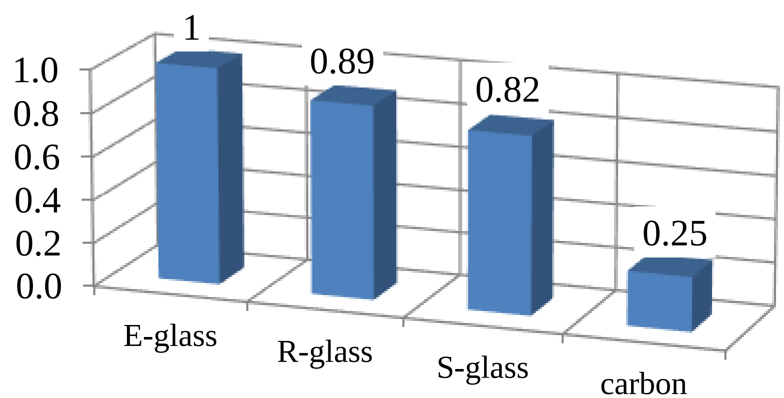
Cracks in the 90 deg ply can propagate to 0 deg plies.

Similar behavior in Long-term fatigue

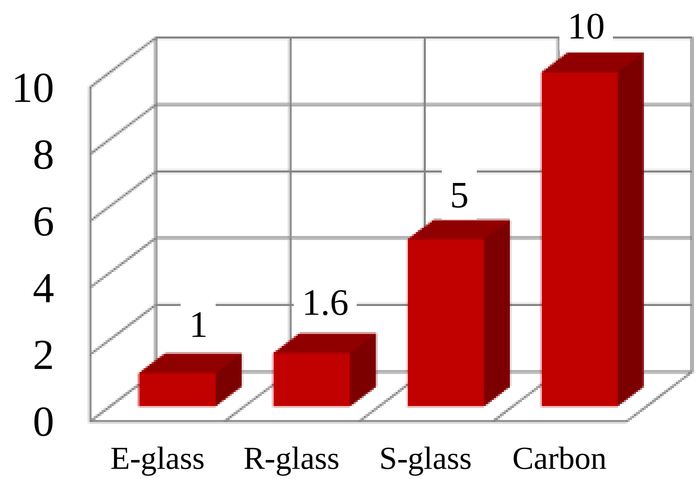
Fibers (Glass & Carbon)

- High stiffness glass fiber : HiPer-tec (3B), Ultrablade (OCV), Innofiber (PPG), etc.

Fiber Types	E-glass	R-glass	S-glass	Carbon
Density (g/cm^3)	2.55-2.64	2.55	2.46-2.49	1.7
Young's Modulus(Gpa)	70-77	84-86	86-90	220
Pristine Strength (Mpa)	3450-3790	4400	4590-4830	4500-5500
Failure Strain (%)	4.5-4.9	5	5.4-5.8	1.2~2.0



- Self weight Tip Deflection, (E-glass=1)

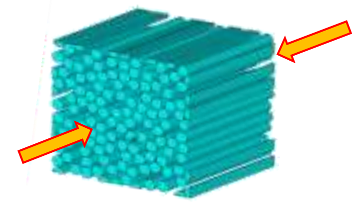


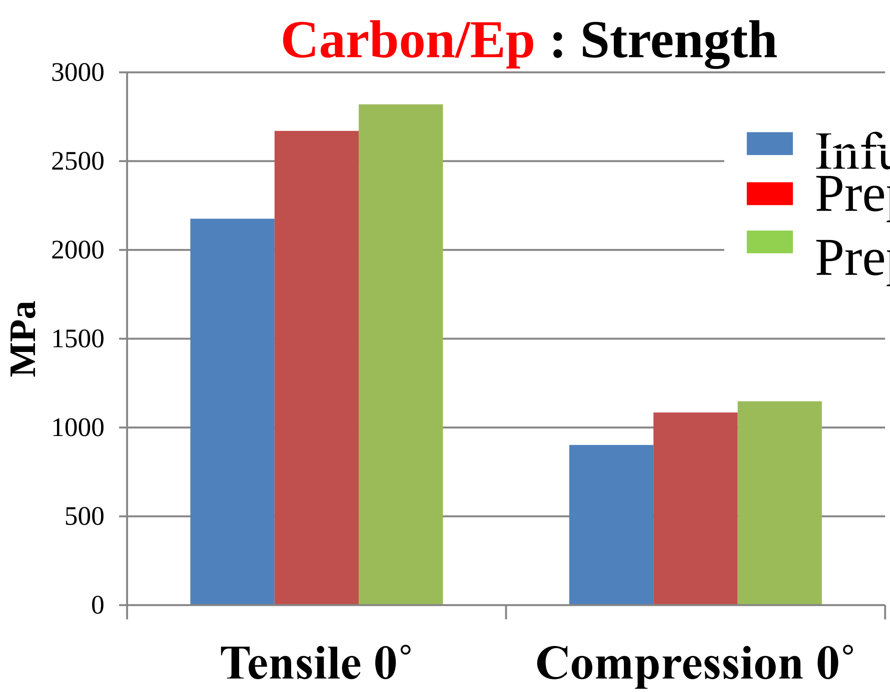
- Material Cost, (E-glass=1)

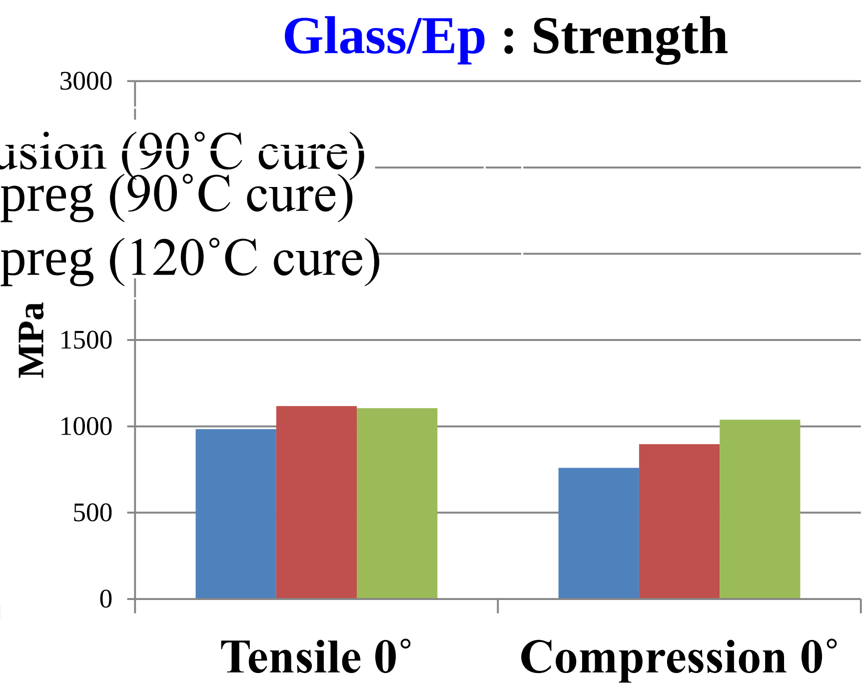
Strength of Carbon vs Glass, Infusion vs Prepreg

- Strength by Infusion (90 C) < Prepreg (90 C) < Prepreg (120 C)
- Tensile strength of Carbon=2 x Glass
- Compressive strength of Carbon= Glass
  - Glass composites is more cost effective than carbon for structure under compression

diameter of glass : carbon fibers
=14 um : 7 um



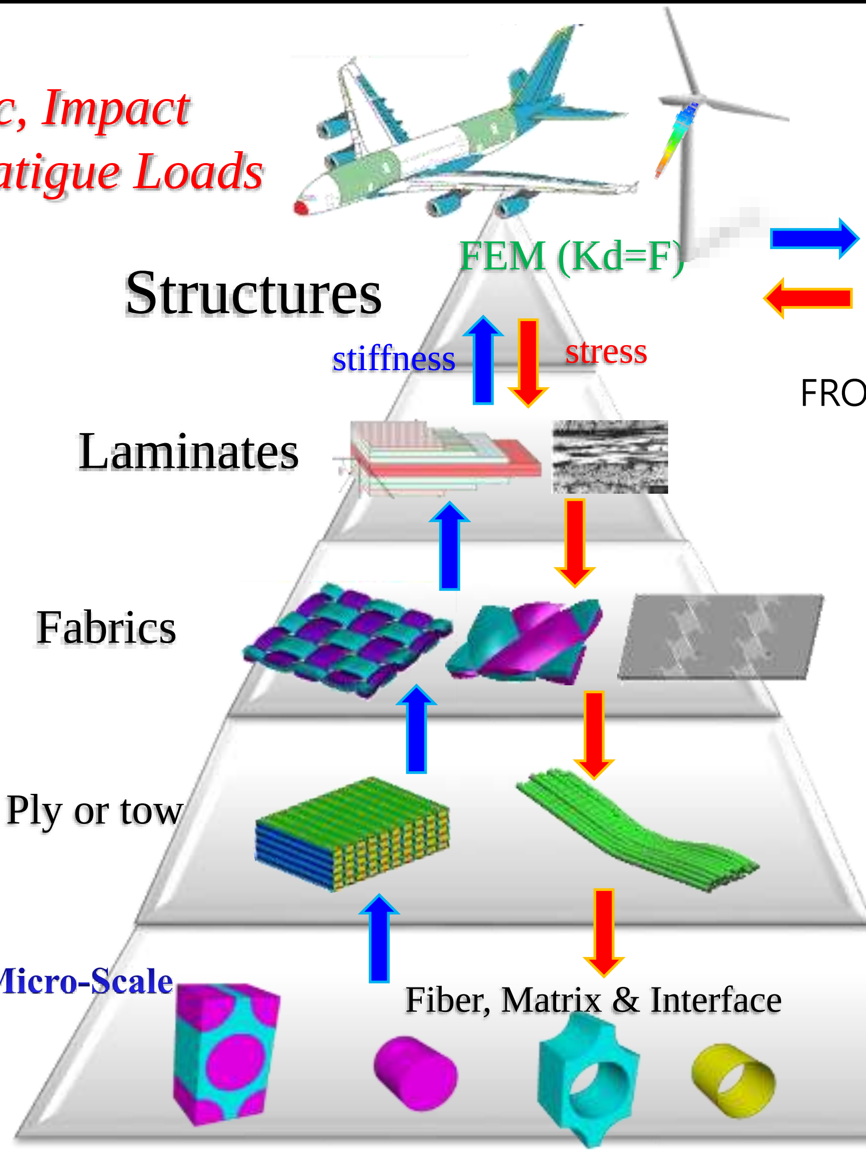




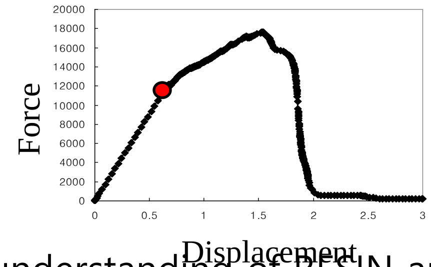
Reference : The use of prepreg to Improve Spar Caps in Infused Blades from HEXCEL

DESIGN based on Simulation; start with understanding of RESIN and FIBERS.

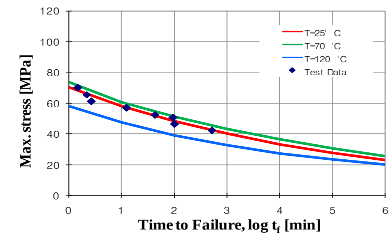
Static, Impact or Fatigue Loads



- Load-Deflection



- Fatigue Life



S-N Curves

FROM understanding of RESIN and FIBERS.

❑ *MultiScale !!*

Predict the composite structural behavior starting with RESIN and FIBER properties; c.f. Convectional approach starts with Ply

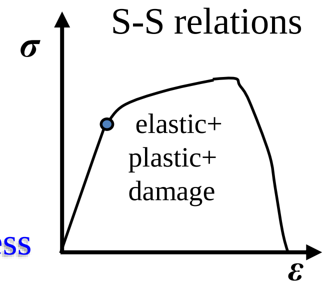
→ *Easy to develop resin*

→ *Minimize number of tests*

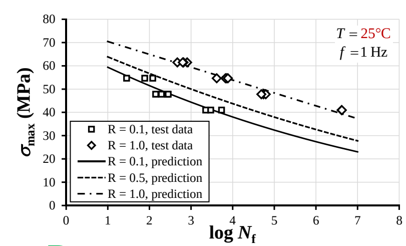
Constituent Properties (Fiber, matrix & interface)

stress

stiffness



S-N curves

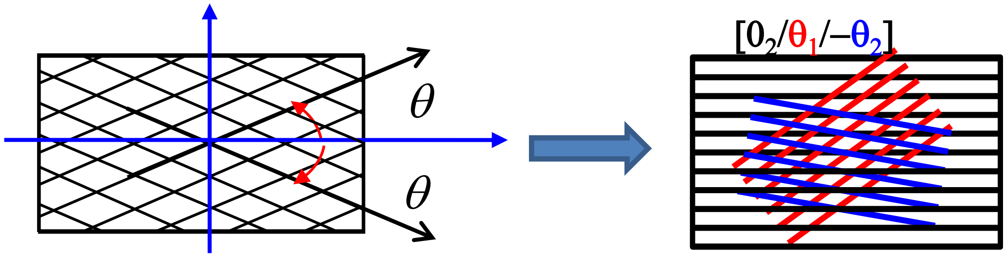


$E=E_o(1-D)$

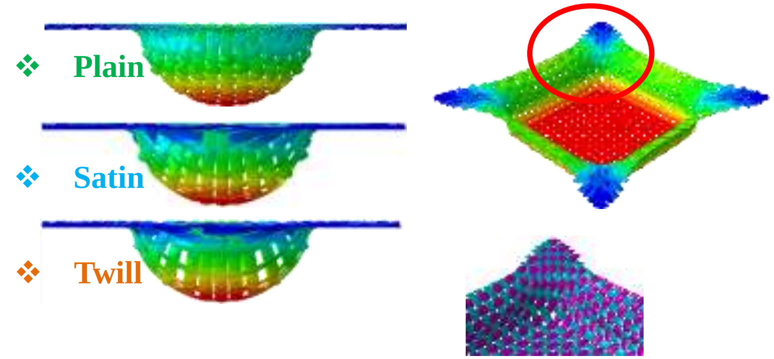
Damage, D

Innovative Design of Composites

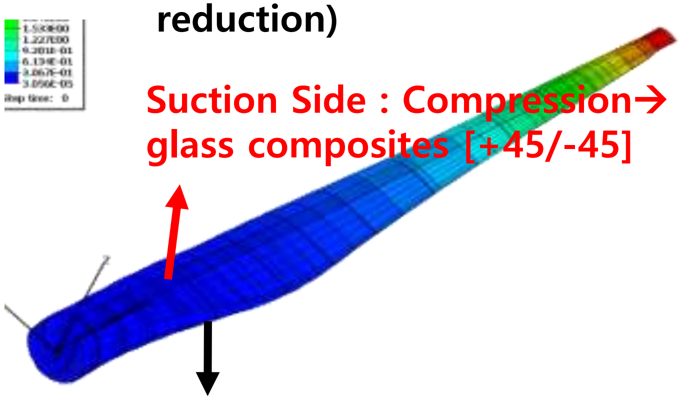
- Unconventional NCF to increase the performance.



- Simulation of Process to maximize the performance

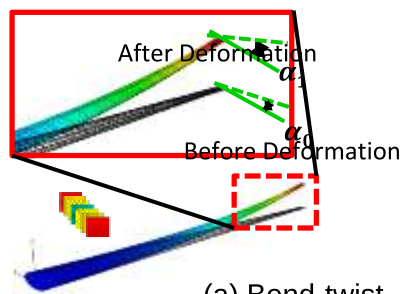


- Wind turbine blades
  - Hybrid skins are more cost effective (up to 5~10 % mass reduction)



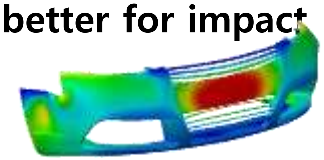
Suction Side : Compression→ glass composites [+45/-45]

Pressure Side : Tension→ carbon composites [+25/-25]

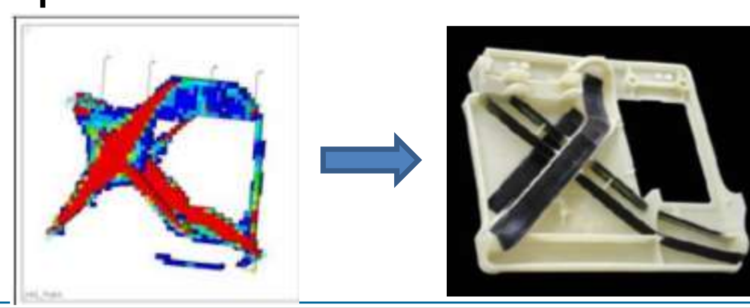


(a) Bend-twist

- Automotive
  - TP composites for better for impact

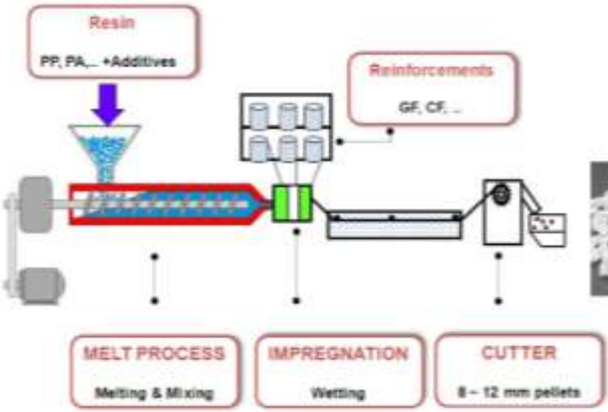


  - Hybridize materials to optimize the performance

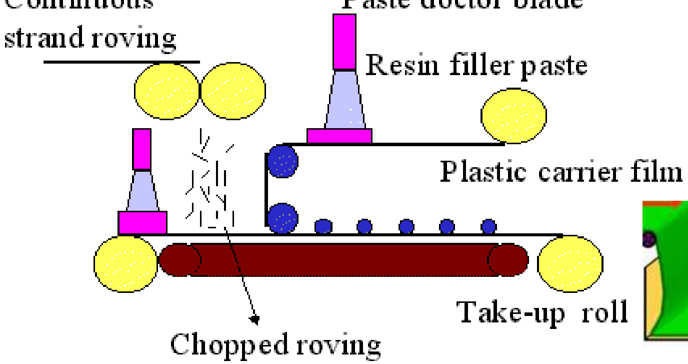


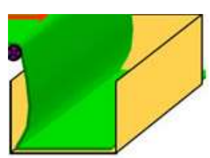
High Speed Process (Compression and Resin injection)

- **LFT (Long Fiber Thermoplastics)**



- **SMC (Sheet molding compounds)**



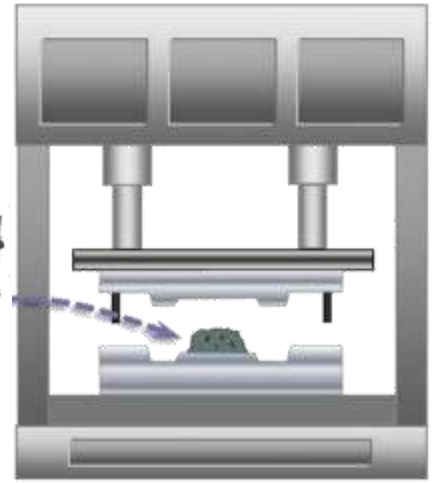


BMC (Bulk molding compounds)

➢ **Compression (temp. and pressure control)**

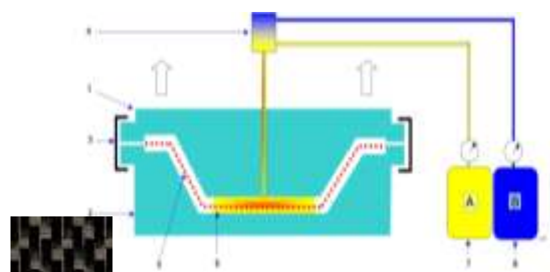
PrePreg

mold



➢ **RESIN injection**

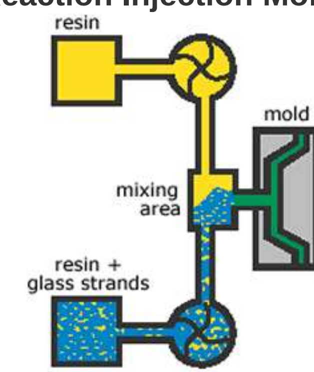
➢ **RTM**



woven fabrics

resin

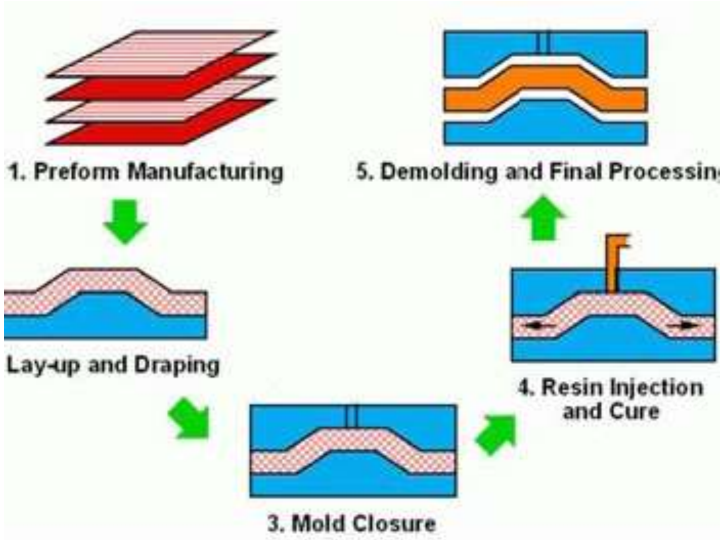
➢ **Reaction Injection Molding**

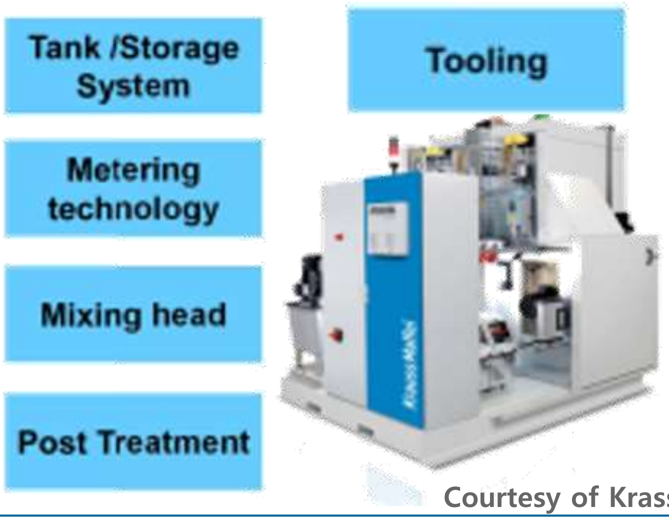


Low RESIN viscosity to prevent Fiber wash-out

RESIN

- **Epoxy** (Momentive, DOW)- **1000 cps, 20~30 min → 2 min.**
- **PA or PA6** (e.g., BASF) – **2 cps, caprolactam** monomer injected with a catalyst and activators. **5 min**, **extremely low viscosity → high fiber volume fraction**. But **high moisture** absorption
- **Acrylic** (**Elium** by Arkema) – Liquid thermoplastic, **100 cps at room temperature,** no heating is needed, **no moisture absorption**. **No expensive equipment**





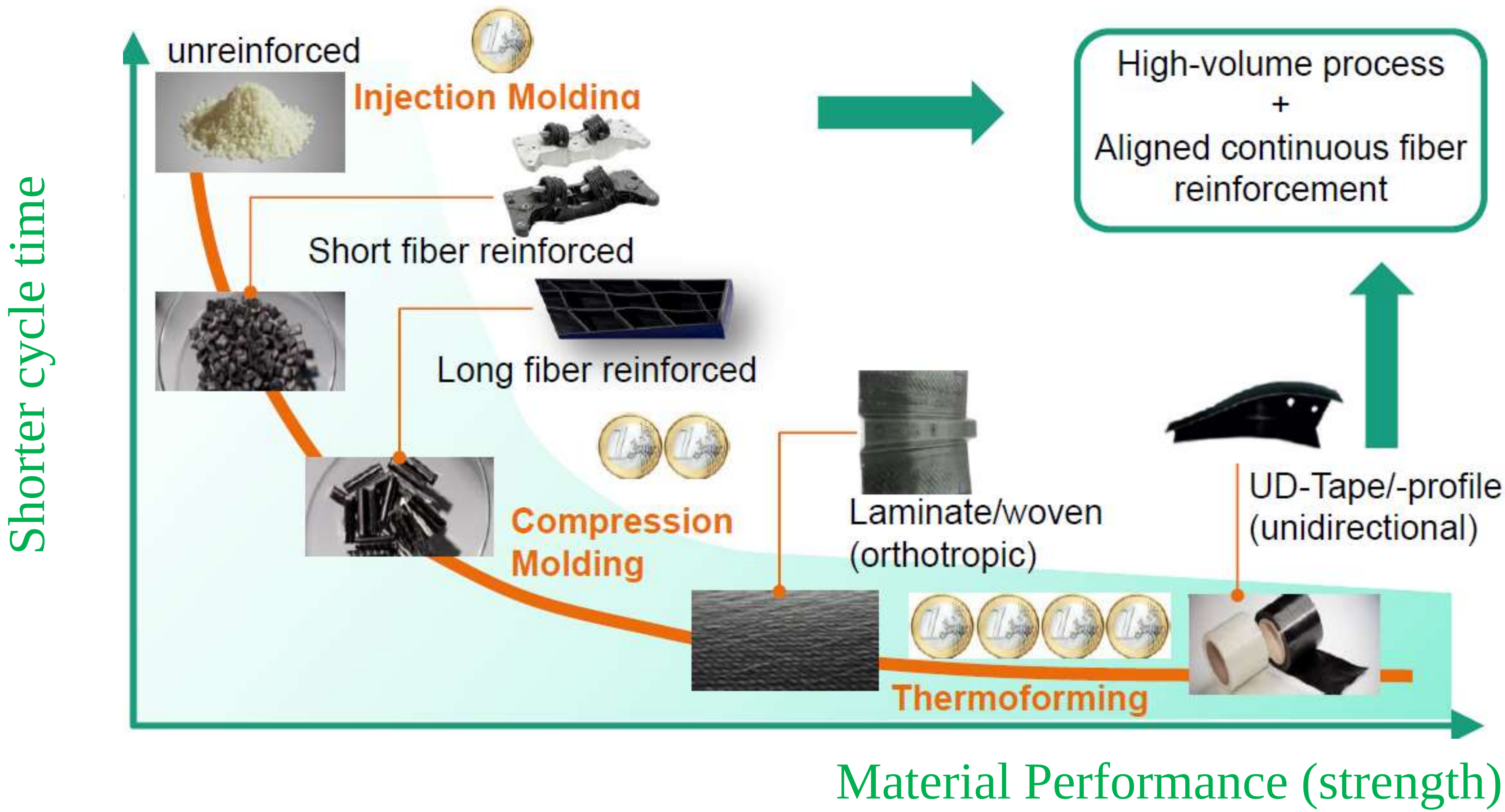
Courtesy of KrassMaffei

PROCESS

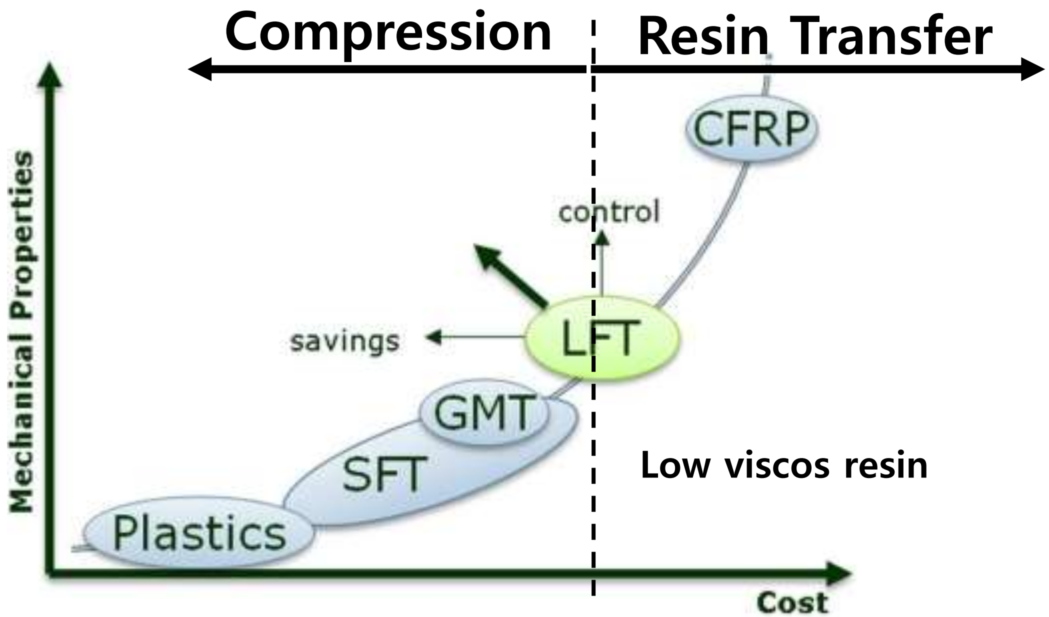
- **RTM** (regular RTM, injecting at 10 to 20 bars —30 to 60 minutes)
- **Compression** (**Gap** or **surface**)-**RTM** (resin injected with mold gap followed by compression**)**
- **RIM** (reactive injection molding)
- **T-RTM** (**Thermoplastic RTM)**
- **HP-RTM** (High Pressure-RTM) up to 150 bar, around 1~3 minutes, **very expensive machine.**

Hybrid Process for short cycle time and high performance

- ❑ Inject Resin or short fiber resin to UD prepreg with reinforcement insert
- ❑ Complicated composite structure with ribs



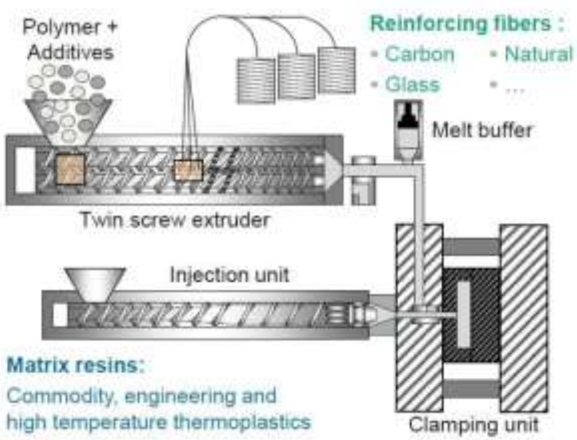
Use LFT (Long Fiber Thermoplastics) for Hybrid Process

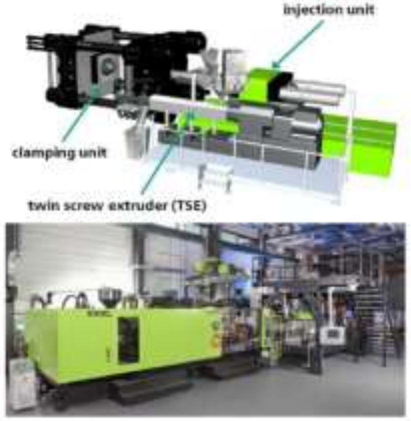


- ❑ LFT has been widely used in automotive market for their strength, stiffness, recyclability and long shelf life (e.g., PP)

- ❑ LFT, possible for both **Compression** and **Resin Injection** **Hybrid** process.

- Direct LFT, followed by Injection Molding

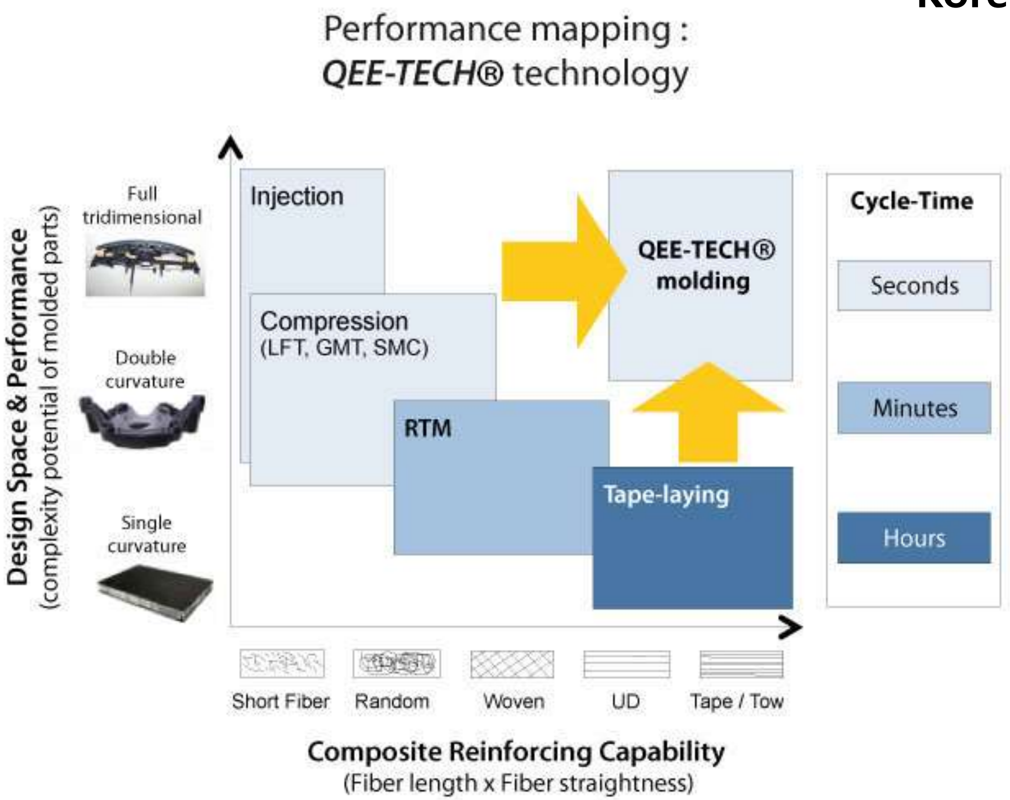


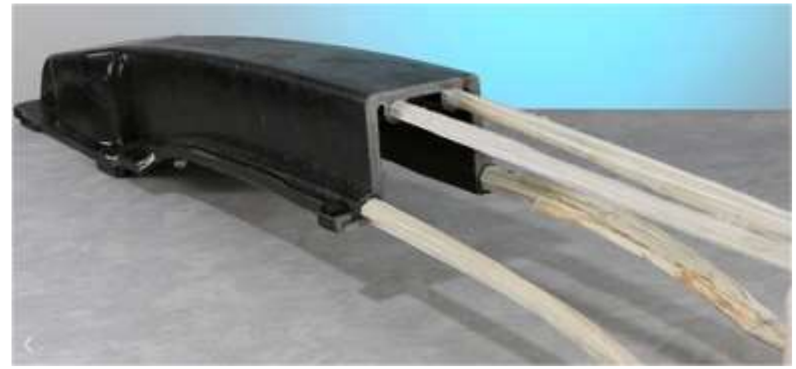


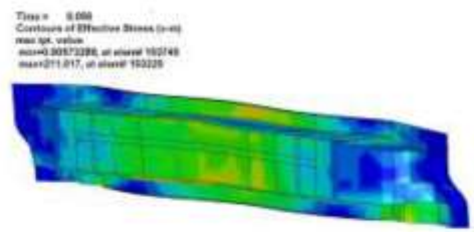
- E-LFT : Compression of Endless fiber + LFT

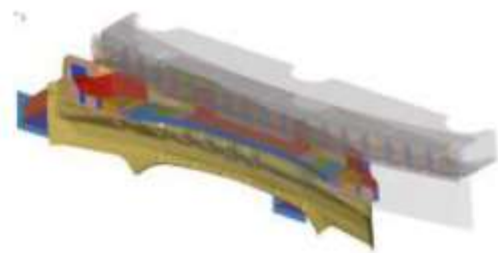
Sample case of IEDP: Tape Layering+Injection

Hyundai-KIA (South Korea), Hanwha (South Korea) and EELCEE (Sweden, Switzerland)



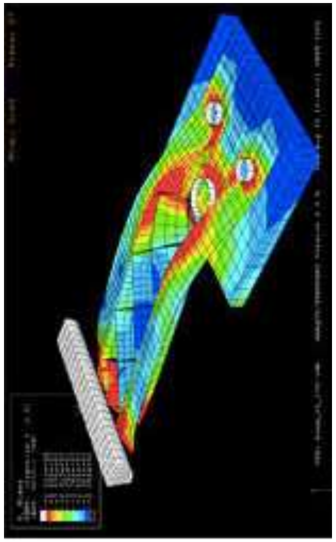






The significance of the breakthrough innovation in the new bumper system lies primarily in a 25-30 % weight reduction, a cost reduction of 10 to 20 % and an enhanced collision performance. The innovation is based on QEE-TECH® technology, which is particularly suited to high volume production.

Sample case of IED : Hybrid Composite Process



Analysis based Design

QEE-Tech preform

Injection Molding

Partial Consolidated thermoplastic Tape (BOIKON)

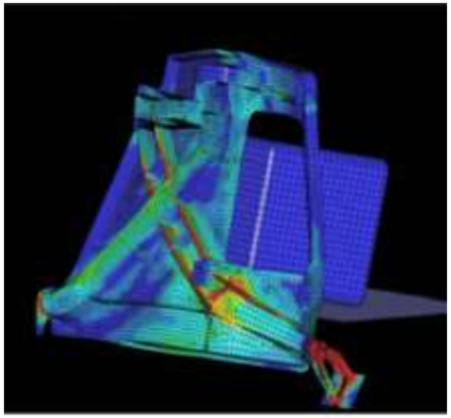
Automated Fiber Placement

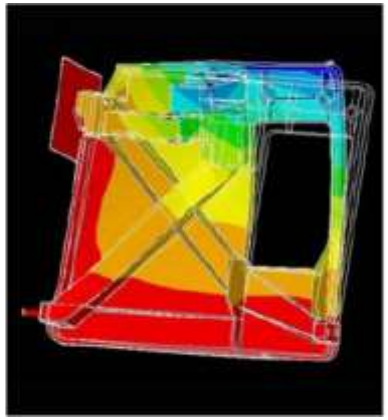
Long fiber thermoplastics

Final product
- High rate production
- High mechanical properties

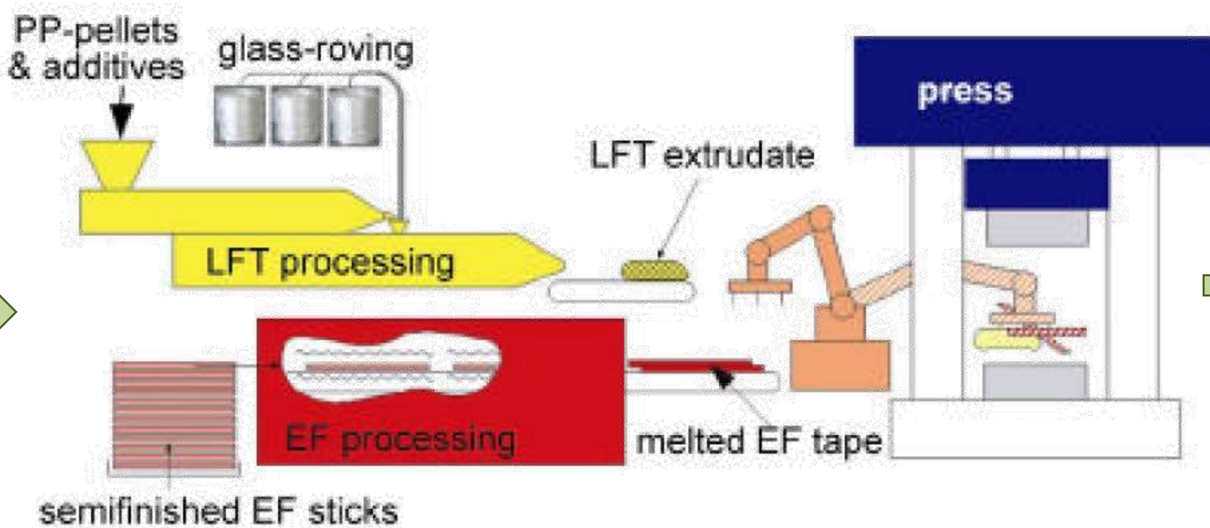
Sample case of IED : Endless Fiber + LFT

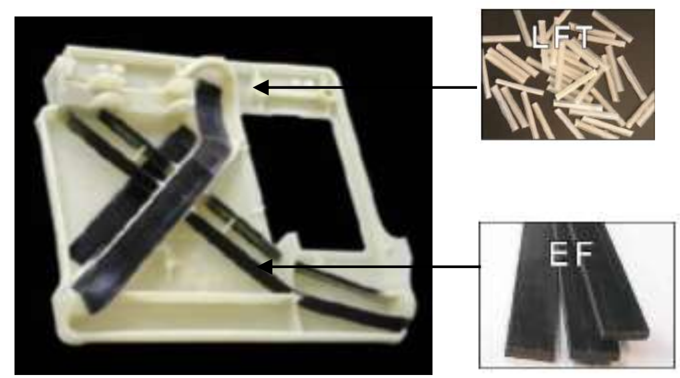
- **Material Selection (Thermoplastics)→ Analysis based Design→ Hybrid Process**





Analysis based Design **CAD for Tool and Mold**



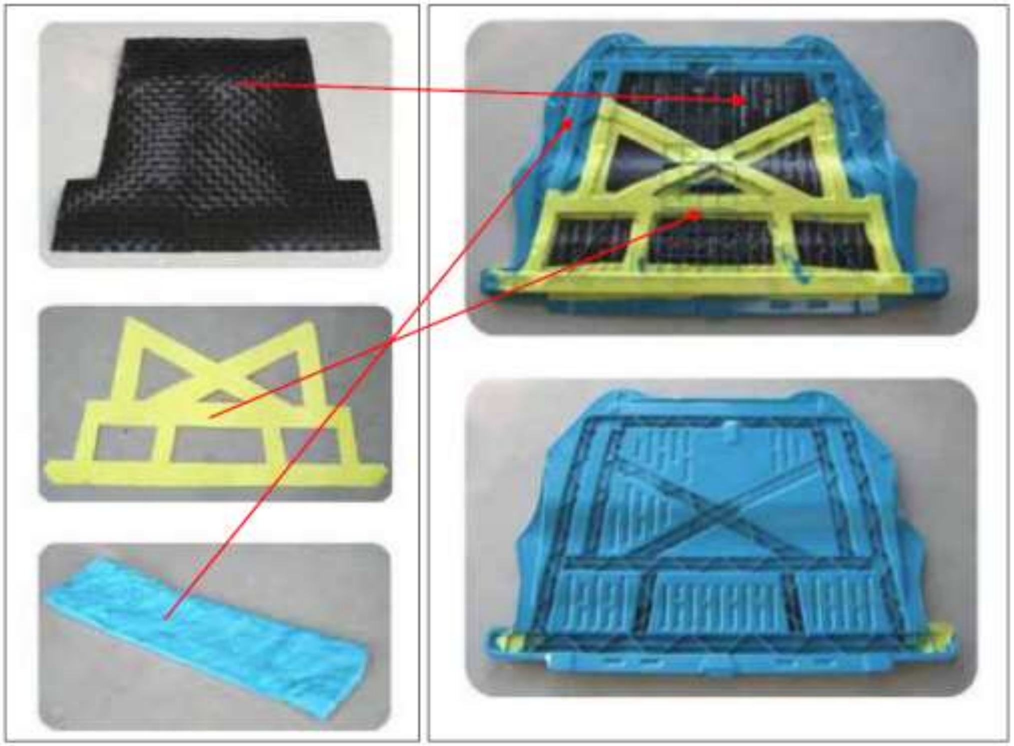


Cited from ESORO

E-LFT (Endless Fiber + Long Fiber Thermoplastics) Hybrid Process

Hybrid Composite Process

Material Hybridization:
Woven fabrics, tailored blank & D-LFT

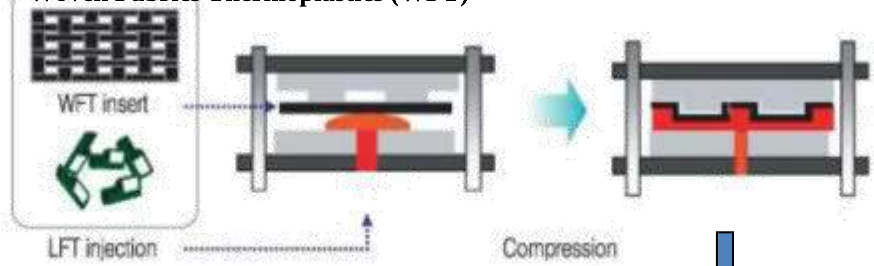


*Figures 2a, b & c (left): Materials used in the shield molding trial were colored to see how they moved in the tool: tape fabric (top, in **black**), tailored blank (middle, yellow), and D-LFT charge (bottom, blue)*

Figures 3a & b (right): How various materials looked in front (top – the side that faced the road) and back (bottom – the side that faced the underside of the vehicle) of molded shield part

Compression process with injection molding

Woven Fabrics Thermoplastics (WFT)



Long Fiber Thermoplastics (LFT)

- Door Plate Module (YF Sonata, HMC)

-Lotte Chemical

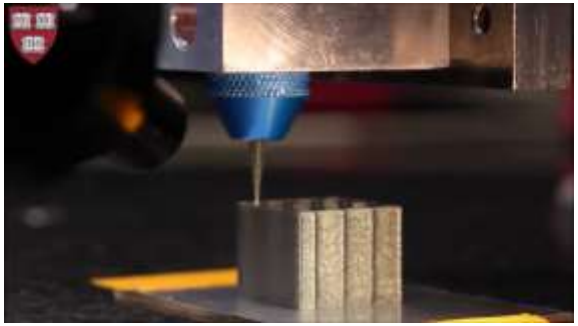
3D-printing (Additive Manufacturing) for Composites

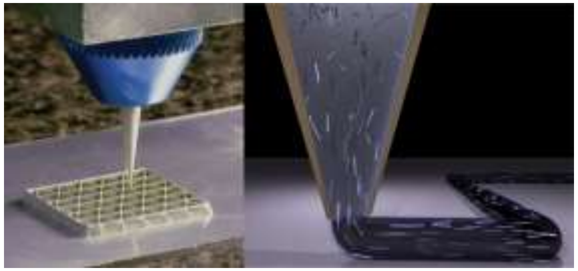
- 3D-print technology is being developed for automatic process of composites.
- High speed consolidation is the key technology.

- Electro Impact (AFP, ATL)

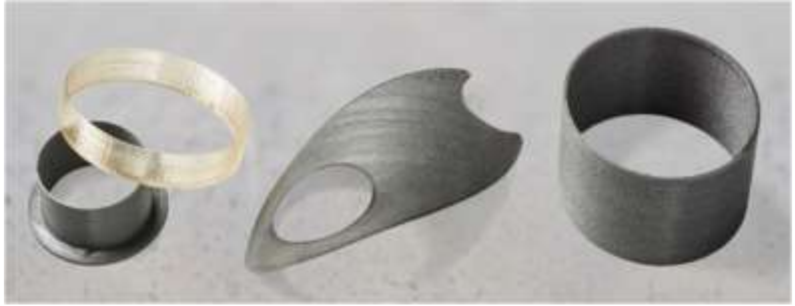
- Orbital Composites

- Harvard Univ.



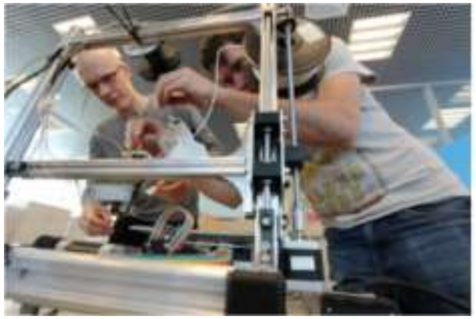


- Arevo, USA



- Composites & Architecture

- Skoltech, Russia



CONCLUSION

- Integrated Engineering Development Process (taking altogether into account material, design and manufacturing process) is effective in developing composite parts with optimized cost and performance

- Innovative resin system? Not only for better mechanical properties but also for Easier, Faster and more Reliable process

- More TP composites are expected due high speed process and recyclability.

- Hybrid process for composites will continue to develop for meeting both short process cycle and high mechanical performance, rather than investing a lot for the new process.

- BIO composites, 3D printing Composites will come…