Additive Manufacturing with Carbon Fiber Composites

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Agenda

• AM with carbon fiber **past**
• AM with carbon fiber **present**
  • Large scale chopped carbon fiber extrusion
  • Continuous carbon fiber FFF
• AM with carbon fiber **future**

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Main Takeaway:
AM has redefined advanced manufacturing over the past 35 years

AM of carbon fiber composites will redefine the future of manufacturing
History: polymer AM was invented in the 1980s

BPM – Direct Jetting
(Bill Masters 7/84)

SLA – Stereolithography
(Chuck Hull 9/84)

SLS – Selective Laser Sintering
(Carl Deckard 10/86)

FFF – Fused Filament Fabrication
(Bill Masters 6/89)
Eli Sachs
- Inventor of binder jetting
- Cofounder Desktop Metal
- $438M Series E funding

Binder Jetting
(Eli Sachs 12/89)

The Production System™ delivers the speed, quality and cost-per-part needed to compete with traditional manufacturing methods. It’s the fastest way to print metal parts at scale.

Binder jetting combined direct jet and powder bed for higher throughput and more material options.
TSS Albany’s Vision: Additive Manufacturing of High Performance Composite Structures

3D printing of polymers and metals didn’t fit our vision, the future was carbon fiber composites.
Early AM Limitations and Growth

Limitations of early AM technologies
1) Low strength (no fibers, poor interlaminar bond)
2) Low throughput
3) Warping (due to shrinkage during cooling)
4) Voids

Despite these challenges, AM is now a >$7B/year industry.

Wohler’s Report 2018
- 528,952 desktop printers have been sold
- 135 companies selling industrial AM systems
- $7.4B revenues

Source: Forbes
AM Materials Strength Comparison

AM Materials - Normalized Specific Yield Strength

- High Strength Steel
- Aircraft Aluminum
- Stratasys FDM Nylon 12CF
- Neat PEEK
- 40% chopped CF PEEK
- Markforged CF/PA
- Arevo CF/PEEK
- Desktop Metal CF/PEEK
- Solvay AS4/PEEK
- Solvay IM7/PEEK

Normalized Specific Yield Strength

- Past
- Present
- Future

- Continuous carbon fiber reinforced
- Chopped carbon fiber reinforced
Cincinnati BAAM, MAAM, SAAM

- 80 lb/hr carbon chopped fiber filled TP
- 20 ft x 7.5 ft x 6 ft

BAAM 3D printed Cobra at IMTS in 2014
Thermwood LSAM

- Up to 500 lb/hr
- Chopped carbon fiber filled TP
- Extrusion and finish milling heads
- 10 ft wide, 5 ft high, up to 100 ft long
Ingersoll Machine Tools - MasterPrint

World’s largest 3D printer

• Work volumes starting at
  • 12m long, 2.5m high, 4m wide
• Extruder modules at
  • 68 – 136 – 454 kg/hr (1000 lb/hr)
• Automatic tool changer
  • finish machining options
• Industrial machine tool precision

UMaine 3D printed boat

• Largest single piece print (Guinness confirmed)
• 76 hr continuous print
• 20% chopped CF/ABS
Markforged

- Founded in 2013
- First commercial continuous fiber FFF printer
- Continuous fiber reinforced PA6
Continuous Composites - CF3D

Tyler Alverado – Cofounder, CEO
- Founded in 2013
- Continuous fibers
- UV cure thermoset
- 3D fiber paths
Orbital Composites

Cole Nielsen – Founder, CEO
- Founded in 2013
- Coextrusion
- 3D fiber paths
- Uses articulated arm robots
- Selling machines, not parts
Arevo

Hemant Bheda, Chairman, cofounder

- Founded 2013
- Directed energy deposition (DED)
- 6-axis robot arm
- Laser heating
- Selling parts, not machines
Anisoprint

-founded 2015
- TP coextrusion
- 3D fiber paths
- Selling machines

Fedor Antonov – founder, CEO

Anisogrid structure
- 60% less wt. than Al
- 25% less than sandwich
- Ultimate force +33%
- Ultimate axial strain -50%

Topology optimized lattice
- 30% less wt. than anisogrid
Arris Composites

Ethan Escowitz - CEO

Riley Reese - CTO

- Founded 2017
- Arevo spinoff
- Automatically form/cut prepreg tape
- Robotically fill molds, Mold final shape
- Selling parts, not machines
9T Labs

- Founded in 2018
- ETH Zurich spinoff
- HIP post process for <1% voids
- Equipment available with a project collaboration

Founders: Martin Eichenhofer, Chester Houwink, Giovanni Cavolina
Robotic continuous fiber printing

- True 3D fiber paths
- 6 axis robot + turntable
- Industrial Siemens 840D control
- Hexcel AS4C carbon fiber
- SABIC ULTEM 1000 resin
- 500m/day potential for 5Km/day
- Selling complete workcells
Desktop Metal - Fiber™

Konstantine Fetfatsidis, Ph. D.
- 2019 SAMPE Young Professional of the year
- Founder Make Composites
- VP Composite Products for DM

- Fiber LT – PA6 continuous fiber reinforced,
- Fiber HT – PEEK or PEKK 60% continuous fiber reinforced, <1% voids
- Continuous fiber/chopped fiber/neat resin interchangeable heads
- 310 mm x 240 mm x 270 mm build volume
- Micro AFP (μAFP) – no post process required

Past
Present
Future
In-situ Consolidation (ISC) of TP Composites
Industrial Workcells with Articulated Arm Robots and Laser Heating

TSS Albany Inc. (Automated Dynamics)
AFPT
Coriolis
Mikrosam
AM of Thermoplastic Composite Structures

- In-situ consolidation (ISC) – no autoclave needed
- Continuous fiber reinforced thermoplastic composite (TPC)
Aerospace ISC Thermoplastic Composite Structures
Cobonded ISC Thermoplastic Composite Structures

- No autoclave
- No adhesives
- No fasteners
AM Tooling for ISC Composite Structures

- Stratasys printed PLA washout tool
- ISC IM7/PEEK structure
AM Enables Topology Optimization/Generative Design
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Future

• Merging of existing technologies
  • Chopped fiber AM
  • Continuous fiber AM
  • ISC
• Topology optimization/generative design of tooling and structures
• Tool-less manufacturing
• Multifunction materials, Embedded sensors, antennas, LSP, deicing, etc.
• Automated in-situ inspection/error correction
• Fully automated fabrication of advanced composite structures
Future

Multifunction materials, Embedded sensors, antennas, LSP, deicing, etc.
Future

Tool-less Manufacturing

Continuous Composites

General Atomics

Branch Technology

ETH Zurich
Thank you for Your Attention

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