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All references in this presentation are available on my personal web-site: www.thinkcompositesllc.com

Transportation Weight Loss Diet Conference
October 24-25, 2012

Carbon fiber intensive automotive body structures can be produced and assembled at rates "nearly" equivalent to stamped and welded steel.

This conference is “dedicated to cutting-edge research and technologies aimed at reducing weight and decreasing carbon footprint, without compromising safety, efficiency, or operational ability.”

Reducing structural mass (materials of choice)

High Strength Steel

Aluminum

Carbon fiber composites

Weight Reduction Projections

Vehicle	Mass (lb.)	Reduction (%)
PNGV Reference Vehicle (Current Steel)	645	
Future Steel Vehicle (FSV) High Strength Steel (HSS)	413	36%
Ultralight Steel Auto Body (ULSAB) HSS	444	31%
Aluminum (R. Scheps, Alcoa)	500	22%
Size adjusted Audi A8 (A. Kelkar, 2001)	352	45%
Carbon Fiber Composites		
Automotive Composites Consortium	285	56%
PNGV - USCAR (Aerospace Sandwich)	192	70%
Aerospace (Solid Laminate)*	160	75%

* Note: <Less than Half the mass of ULSAB and FSV

Which is more important?

Cost,

I believe the automotive industry is so focused on material cost that they've forgotten what the effect of mass production has on cost... "Build at high rate and unit cost will go down".

or the ability to achieve high production volumes?

$Cost... $Cost... $Cost... or Automatability?

Henry Ford and the Assembly Line

“Mass production via assembly lines is widely considered to be the catalyst which initiated the modern consumer culture by making possible low unit cost for manufactured goods.”

When, we demonstrate the ability to produce carbon fiber intensive automotive BiW at high volume, significantly lower unit cost will be realized.

The ability to produce at high volume is the most important!

What is high volume, when it comes to the use of carbon fiber in a primary structure?

Aerospace

- 20-30 aircraft per month? (B787 or A350 projected)
- **~367,000 major components (B737)**
- ONE (1) per day

Automotive (BiW & Chassis)

- 1,000 per day (per assembly plant)
- **~200 major components (FSV & ULSAB)**
- ONE (1) per minute

Can high volume production of complex primary structures using carbon fiber be achieved?

Automation of Aerospace and Automotive Primary Structure?

- Cost, cost, cost of Automation
  - Aerospace volumes are too low for major investments in automation
    - ~367,000 components requiring automation (B737)
    - (Moderately) Tolerant of labor intensive operations
    - ~ 80% labor / 20% material
  - Automotive production volume justifies automation
    - ~200 components requiring automation
    - (Exceptionally) Adverse to labor intensive operations
    - ~ 20% labor & 80% material

Can high volume Carbon Fiber Automotive BiW be achieved?

Yes, it will be…

Using a derivative of thermoforming and compression molding
Closest to the tandem press-line, progression die stamping & forming used today in the automotive steel stamping industry.

The "Progression Compression Forming" process. (PCF)

(TM, Patent Pending)

Yes! High production volume CF/E is possible!

What is the material form?

Epoxy preimpregnated uni-directional carbon fiber.

Heavy B-Stage, highly characterized for formability at various temperatures and degree of cure / (B-Stage).

Exceptionally similar to current aerospace primary structure grades.

Refer to: National Center for Advanced Materials (NCAMP) database (www.niar.wichita.edu/coe/ncamp.asp)

What is B-Stage?

Macro-molecular polymer chemistry is not much different from... Metallurgy.

(It's not an old technology, Epoxy since ~1936, ~75 years old)

Just think about work-hardening steel, but we're increasing molecular weight

Metallurgy

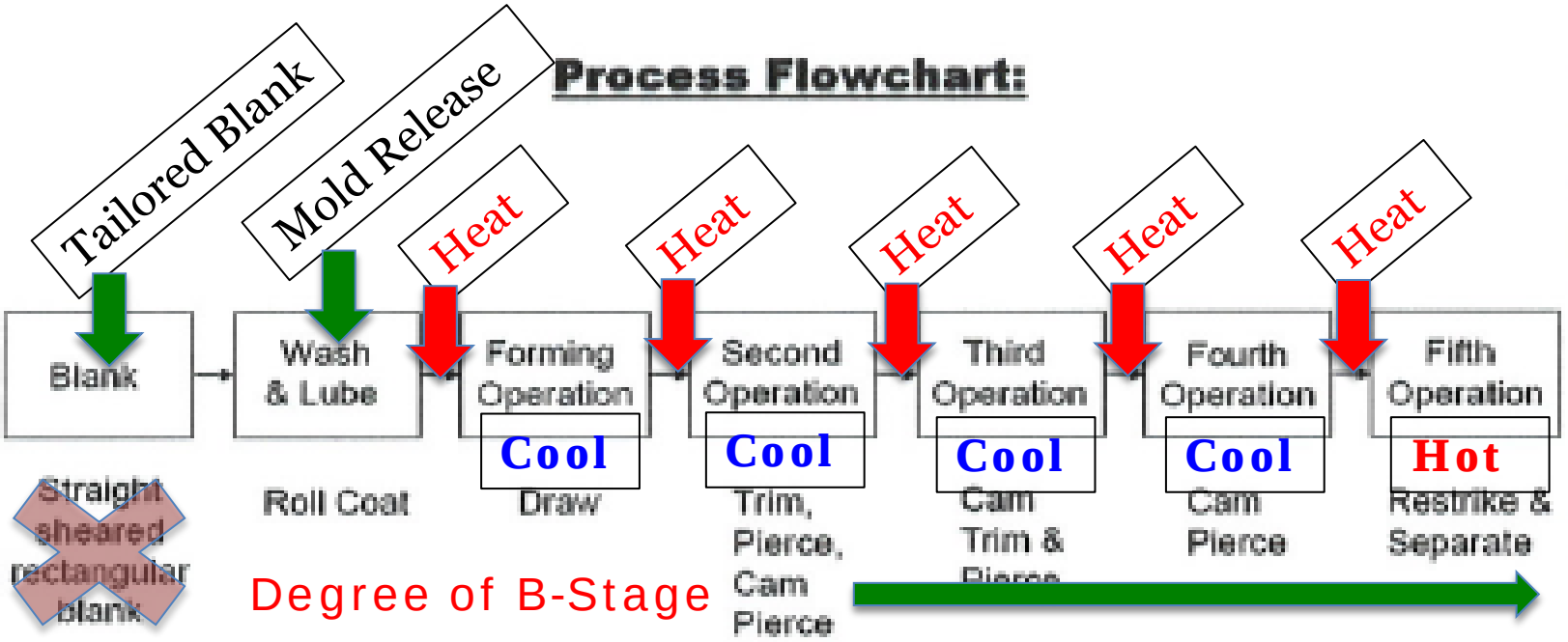
The first evidence of human metallurgy dates from the 5th and 6th millennium BC

Refer to: "What is B-stage" .ppt (Lasell, 2010)

"B-Staging of Toughed Epoxy Composites" (E. Bravo, Arlon, 2001)

The Progression Compression Forming (PCF) Process (TM, Patent Pending)

STAMPING PROCESS DESIGN



Gradually increasing the degree of cure of the epoxy as the components travel down the PCF press-line, formability less at higher degree of cure.

Automotive Steel Partnership
Automotive High Strength Steel

Tailored Blank Manufacturing Process?

Tailoring:

Thickness, Grain Direction – Fiber Orientation, Shape and the Degree of B-Stage

Refer to “Tailored Blank Process” .ppt

The Tandem “PCF” Press-line Operation

- Plan on 5 Progression dies
- Plan on a tandem press-line
- Maximum pressures ~500 psi
- Temperatures 375 to 400F
- Cool down full form cooling fixtures

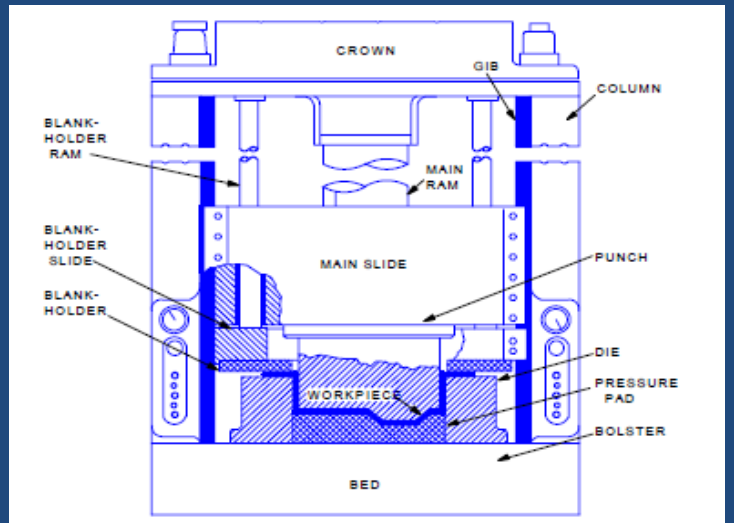
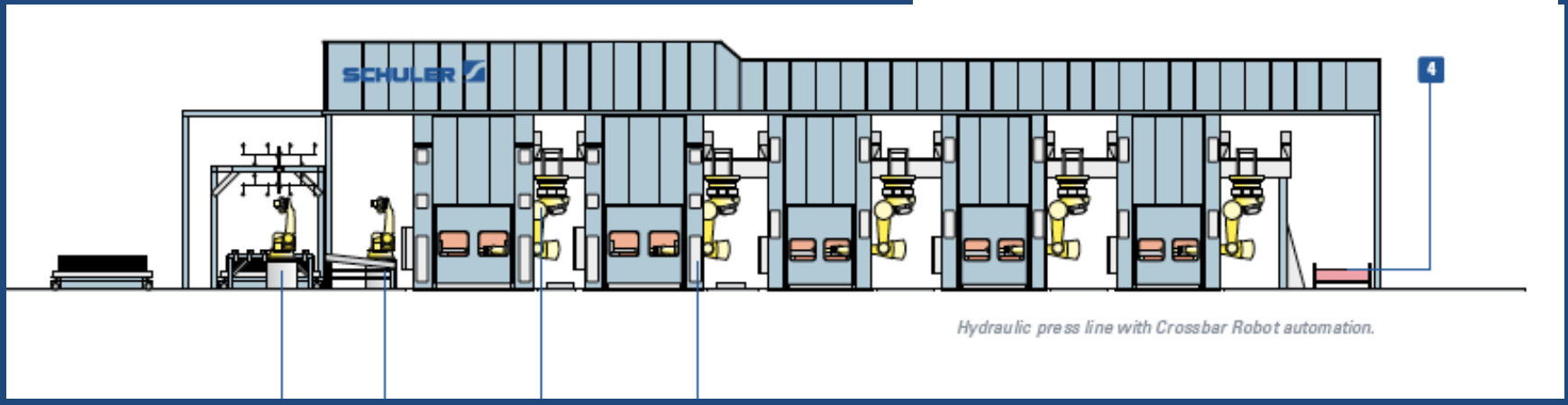


Figure 4.1.4.2-1 Major components of a hydraulic press and die



Hydraulic press line with Crossbar Robot automation.

The Progression Process (6 Stations)

Six-station press line with ServoDirect Technology and Cross-bar Feeder automation.
The maximum output rate is 17 strokes per minute.

Note the rate steel is being formed today, our objective is to demonstrate two (2) strokes per minute.

First (4) Stations of the PCF Process

- The tailored blank goes into the die hot (semi-flexible)
- Part comes out of the forming die warm/cool (stiff)
- "Near thermoforming"
  - Melt/soften the resin (area of bend) and harden after forming.
  - Start and then immediately stop the progression of cure.
  - Selective area B-staging, fold lines & deeper draw channels
  - We will control the **THICKENING** of the epoxy
    - Degree of B-staging will be more like the copper-clad laminates of the Printed Circuit Board industry

Punch, Pierce & Trim (PP&T)

- When Carbon Fiber Epoxy is hot, it is soft and flexible

  (B-staged, not completely cured)

  - Middle 3-4 stations will accommodate PP&T
  - Additional folding, forming and shaping
  - Tailored curing / tailored B-staging
    - Cure (harden) less, over there
    - Cure (harden) more, here now
    - Cure (harden) there later

  - (Refer to: “What is this term Melding?” .ppt)

Last Die in the PCF Line

- Restrike, Draw, Form & Final Thickness
  - Spring-back compensation
  - Final Trim (if required)
- **Heal** (re-bonding) all minor delamination's
  - Caused during punch, pierce and trim
- Last full form Progression Compression Forming stroke
  - Hot material going into a Hot Mold
  - Highest part temperature in the die-line
  - Highest forming pressure in the die-line
  - Part exits the die-line hot (~200ºC)
  - Immediately Placed on to a Full Form Cooling Fixture
    - Restraint Applied as Required
    - 6-Sigma Driven

The Progression Compression Forming (PCF) Process (TM, Patent Pending)

Exceptionally Similar to
Existing Automotive Sheet Metal (Steel)
Progression Stamping & Forming Process

- Will utilize (most of) existing tandem press lines and material handling robotics

Steel & Aluminum

The Parts Do NOT Have to be Fully Cured Exiting the PCF press-Line

- Components Must Have Dimensional Stability
  - Off of the Die-Line
  - After cool-down

Those of you whom have worked with the low temperature cure, Tooling grades of CF/Epoxy, know what I mean about "not completely cured yet", but can be post-cured without any significant supports or restraints

- The completion of the cure "hardening" process will happen after the body structure is assembled.

- All Steel and Aluminum BiW are / have to be thermally processed after assembly today.

Refer to "Baking after Body Assembly"

Unsupported Post Cure, Bake Hardening and Stress Relief?

Is a Justification required?

Note: Automotive Composites Consortium has been working with a limitation requiring 100% cure off the press-line.

Refer to: “Baking after Body Assembly” .ppt

Producing the BiW Assembly and Joining at One (1) per minute?

- Can we assemble and join all of these CF/E components at these same rates?
  - Yes, We can!
  - Assembling a complex automotive BiW at the required (1) per minute rate is possible.

Refer to: “E-Beam Spot Weld Bonding” .ppt

Thank you

Questions?

References available at: www.thinkcompositesllc.com

Join the growing consortium at:

The Composites Center of Excellence @ Raspet

Developing and demonstrating cost effective design and manufacturing technology for high volume production of ultra-light, composite intensive structures for the transportation industry (aerospace, automotive, truck & rail)

MEP.ms Manufacturing Extension Partnership of Mississippi

A Closer Look at Manufacturing in Mississippi

RFRL

RASPET FLIGHT RESEARCH LABORATORY

CAVS EXTENSION Mississippi State University
Center for Advanced Vehicular Systems

THINK COMPOSITES, LLC.

JAMES WORTH BAGLEY COLLEGE OF ENGINEERING
MISSISSIPPI STATE UNIVERSITY

HPC² High Performance Computing Collaboratory

MISSISSIPPI POLYMER INSTITUTE

Mississippi Technology Alliance

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