Evaluation of Friction Stir Welding Process and Properties for Aerospace Application: Standards and Specifications Development

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Joint Advanced Materials and Structures (JAMS) CoE
Technical Review Meeting
Hosted by CECAM at Wichita State University
July 21 – July 22, 2009

The Joint Advanced Materials and Structures Center of Excellence

Outline

- SAE Material Specs/Stds for FS Materials
  - **SAE Committee Coordination**
  - Material Specifications Roadmap Approach
  - Draft Roadmap

SAE Material Specs/Stds

- SAE Committee Coordination
  - AMEC Meeting No. 203 (October 29, 2008)
  - AMEC Meeting No. 204 (January 29, 2009)
  - AMEC Meeting No. 205 (March 25, 2009)
  - SAE AMS Committee D Presentation (March 31, 2009)

SAE Material Specs/Stds

- Committee Coordination
  - AMEC Meeting No. 203 (October 29, 2008)
    - M. Niedzinski announced the FS spec/standards initiative and introduced D. Burford
    - D. Burford provided overview (verbal)
    - D. Burford was elected to committee
    - Approval was granted to add formal presentation of proposal to agenda in next AMEC meeting

SAE Material Specs/Stds

- Committee Coordination (cont'd)
  - AMEC Meeting No. 204 (January 29, 2009)
    - Draft roadmap proposal presented & discussed
    - Approval was granted to draft friction stir (FS) specs
    - The committee chairman recommended that we use an aluminum forging spec as template for initial draft
    - An update was scheduled for the next AMEC meeting

SAE Material Specs/Stds

- Committee Coordination (cont'd)
  - AMEC Meeting No. 205 (March 25, 2009)
    - A presentation of the refined draft roadmap was given & discussed
    - Approval to draft a roster for an AMEC subcommittee was granted
    - We were scheduled to provide update to SAE AMS Committee D Presentation the following week (March 31, 2009)

SAE Material Specs/Stds

- Committee Coordination (cont'd)
  - SAE AMS Committee D Presentation (March 31, 2009)
    - D. Burford was introduced to the committee by AMEC committee chair, Al Patterson
    - D. Burford presented and discussed roadmap approach for FS material specs
    - The presentation added to committee minutes

Outline

- SAE Material Specs/Stds for FS Materials
  - SAE Committee Coordination
  - **Material Specifications Roadmap Approach**
  - Roadmap

Materials Produced by FS

- Friction Stirring (FS)*
  - Fine grain size (<15 μm)
  - Equiaxed grain shape
  - Presence of very fine second-phase particles to inhibit grain growth
  - Large fraction of high-angle grain boundaries

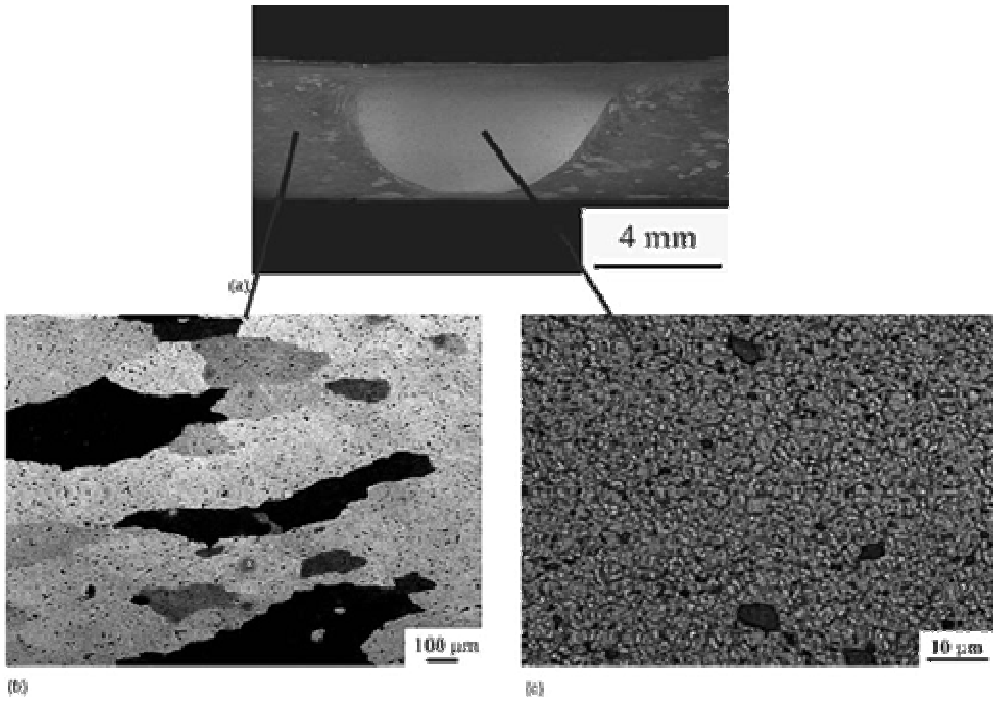
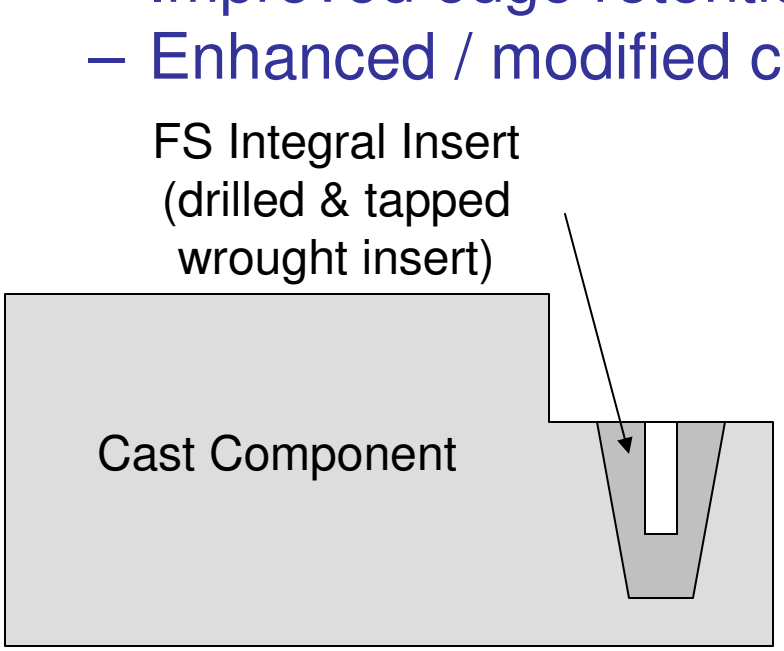


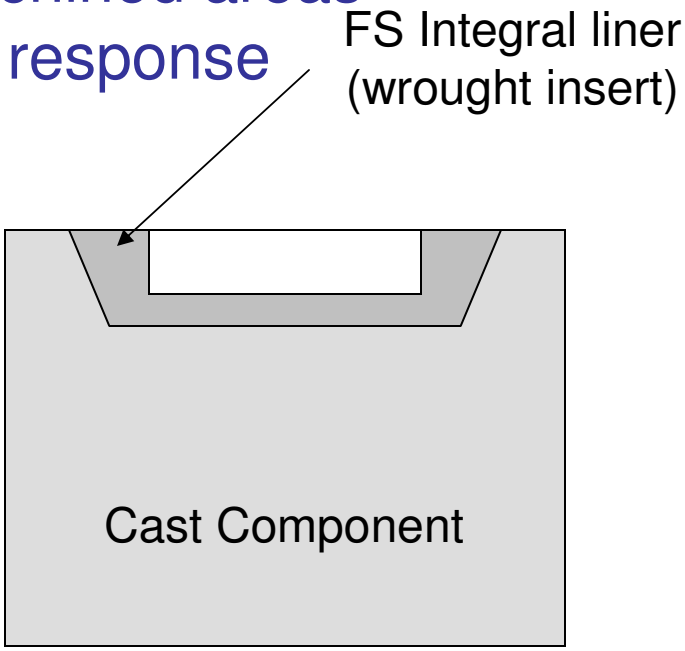
Fig. 14.3 (a) Friction stir processed 2024; (b) & (c) Comparison of as-rolled and as-FSPed microstructure

* R. Mishra & M. Mahoney, "Friction Stir Processing," in *Friction Stir Welding & Processing*, © ASM International, 2007, pp 309-350

Materials / Product Forms

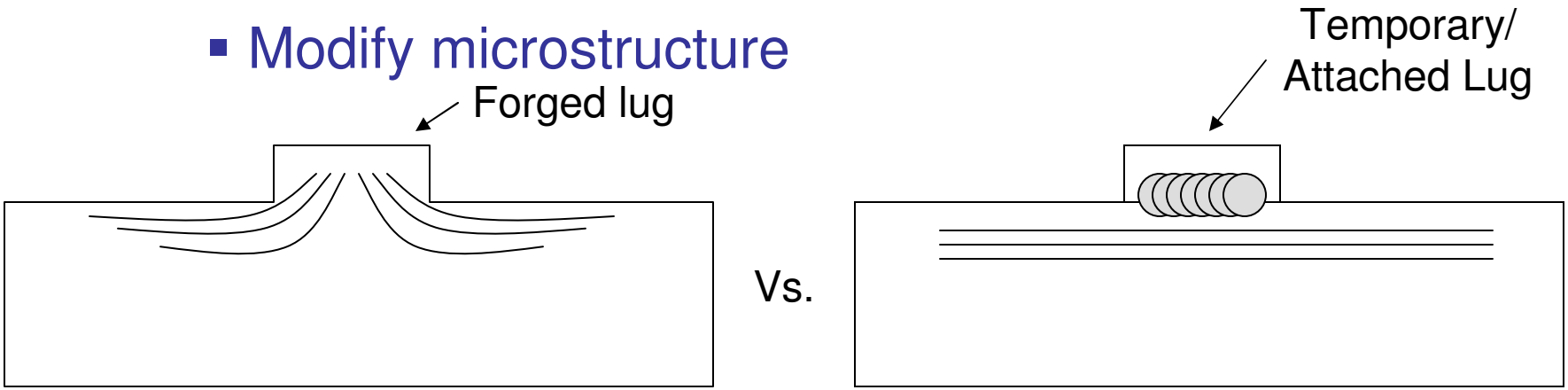
- FS Inserts in Castings
  - Repair / healing of pores
  - Wrought material for fasteners
  - Improved edge retention of machined areas
  - Enhanced / modified corrosion response





Unique Product Forms

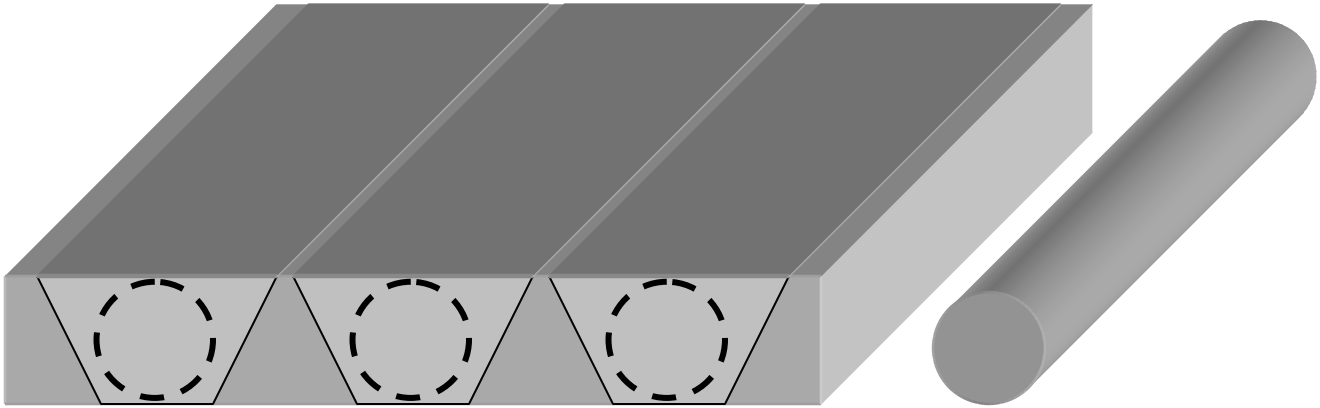
- Forging End Grain Control
  - Manufacturing Assist
    - Removable tabs
    - Reduce complexity of forgings
    - Reduce end grain exposure
  - Termination operation
    - Modify microstructure



Unique Product Forms

FS rod material (e.g. fastener fabrication)

- Fine, equiaxed microstructure
- Not producible by extruding, wire drawing, etc.

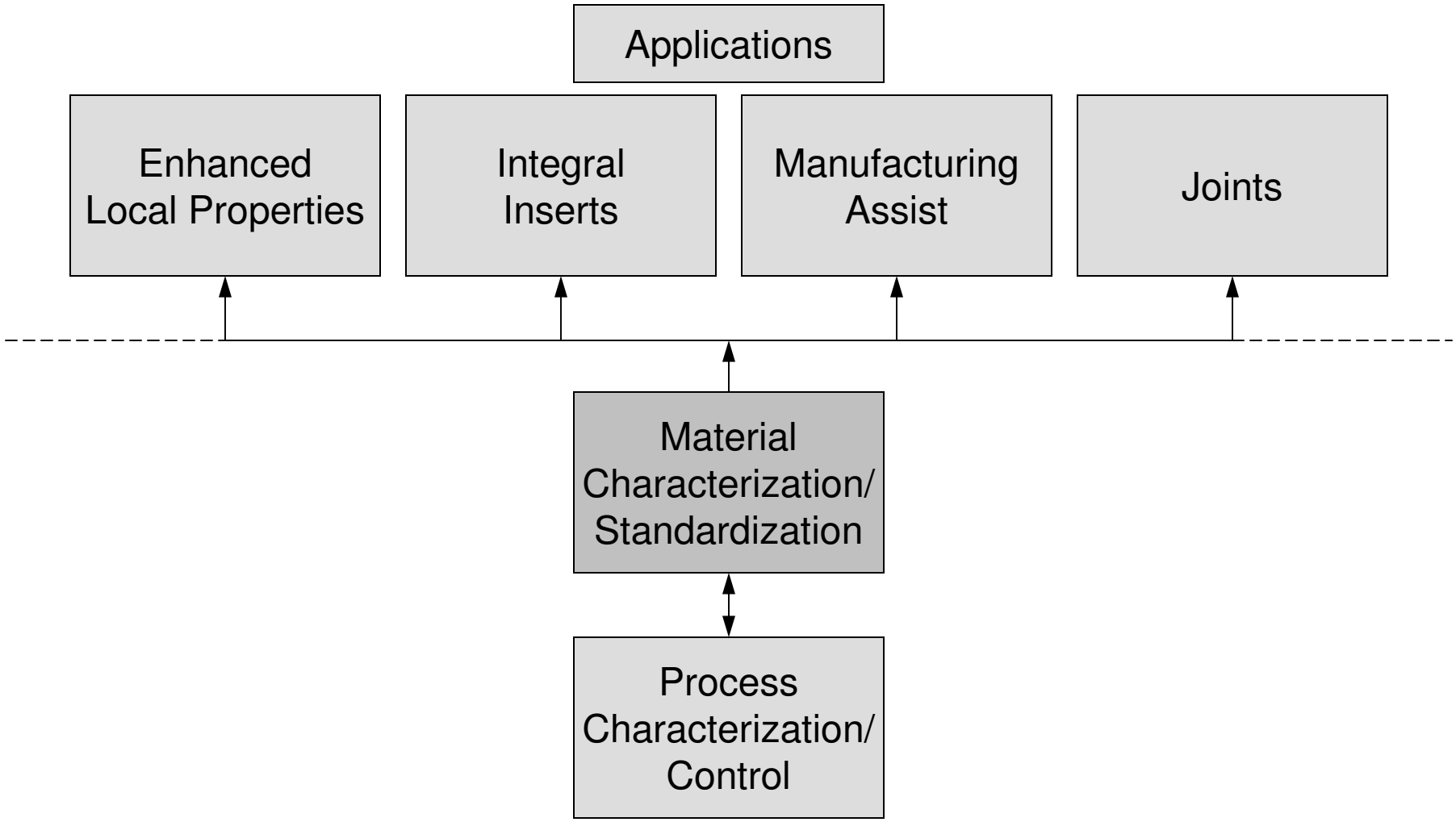


Boeing Patents US 6,843,404 & US 6,854,634

SAE Material Specs/Stds

- Material Specifications Roadmap Approach
  - **Material properties / characterization**
    - Grain morphology
    - Mechanical properties (static, dynamic, etc.)
    - Response to corrosive environments
  - Support joint property specs (etc.)
    - Account for individual material segments
    - Characterize combination of mechanical properties

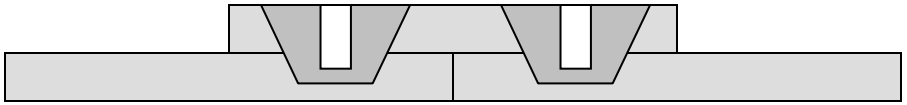
SAE Material Specs/Stds



Joint Construction

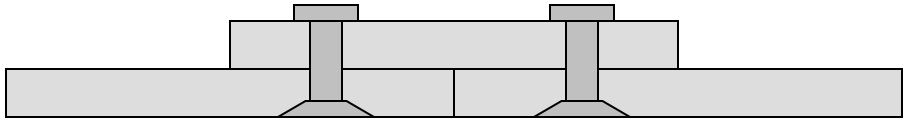
Integral Fasteners/Joints

Insert fastener through mechanical stirring



Installed Fastener Joints

Insert fastener through mechanical drilling and compression



Materials Produced by FS

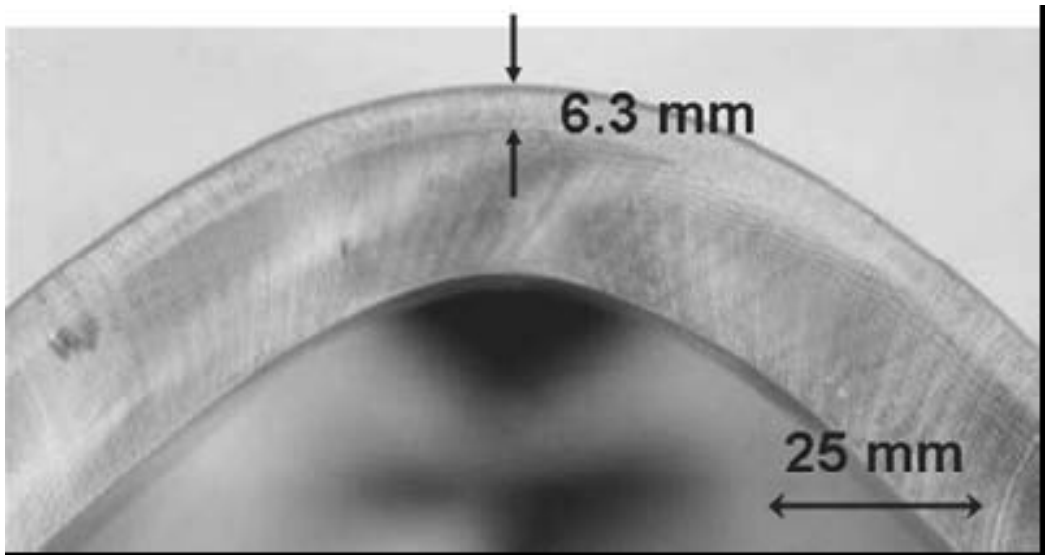


Fig. 14.14 Illustration of the friction stir processing depth (6.3 mm, or 0.25 in.) and the ability to bend 2519-T87 Al ~85 ° at room temperature

* R. Mishra & M. Mahoney, “Friction Stir Processing,” in *Friction Stir Welding & Processing*, © ASM International, 2007, pp 309-350

Materials Produced by FS

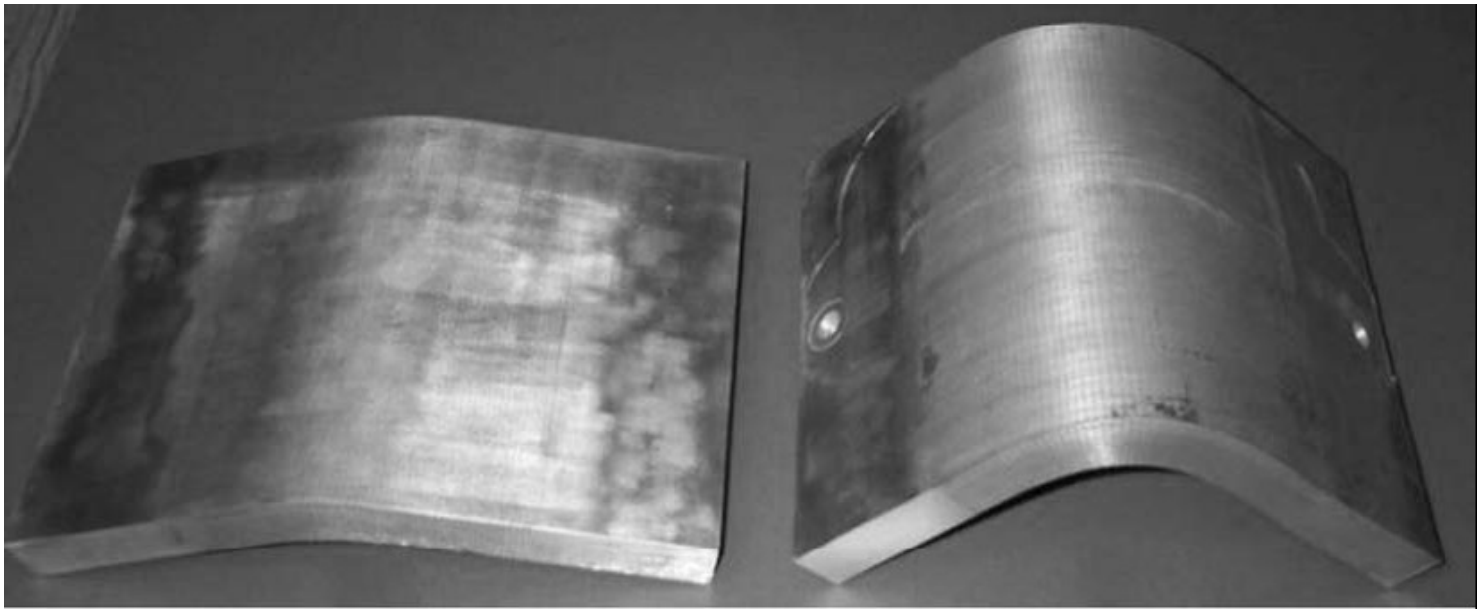


Fig. 14.25 Plane-strain bending in 50 mm (2 in.) thick 6061-T6 Al. (a) Parent metal bent to 27°, with cracks initiating on the tensile surface. (b) Friction stir processed 6061-T6 Al bent to 85° without cracking. Circle grid analysis of the surface strains showed that the negative minor strain at the crown was less than 1%.

* R. Mishra & M. Mahoney, "Friction Stir Processing," in *Friction Stir Welding & Processing*, © ASM International, 2007, pp 309-350

Materials Produced by FS

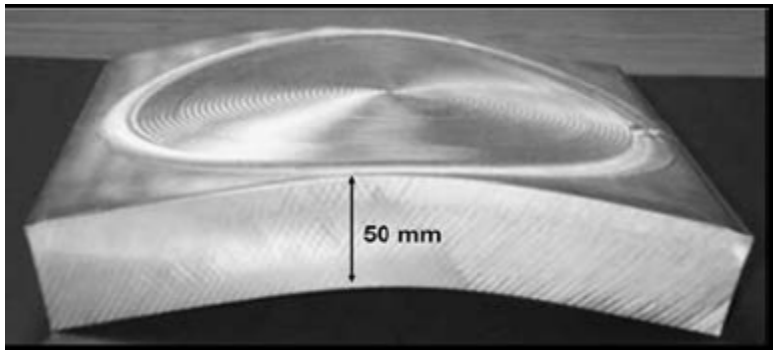


Fig. 14.23 Spiral raster pattern in 50 mm (2 in.) thick friction stir processed 7050-T7451 Al bent 16° at room temperature

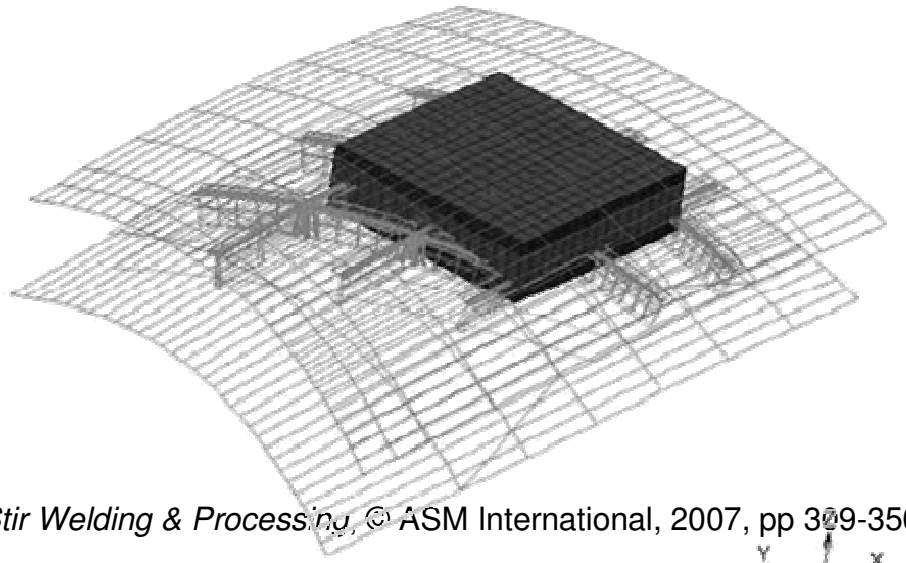
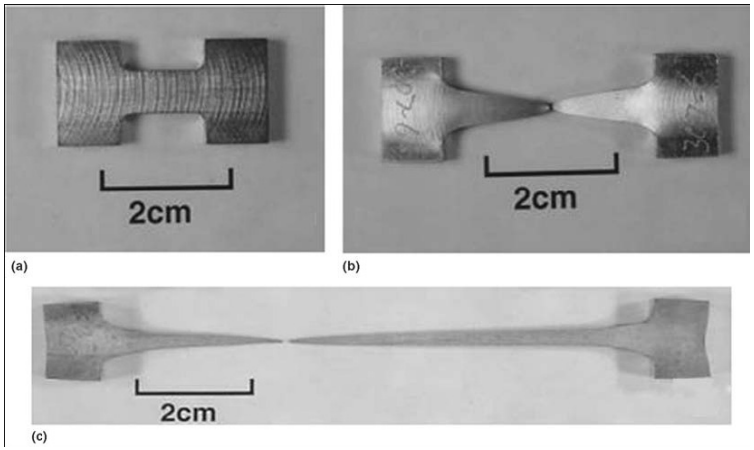


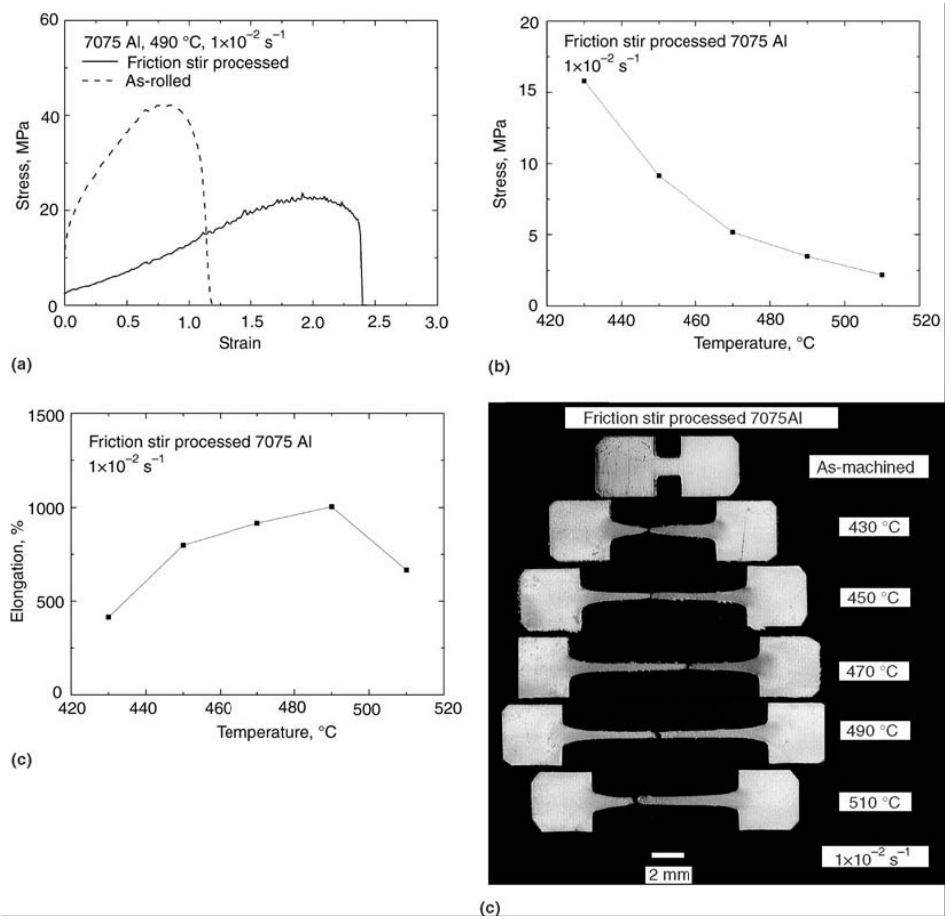
Fig. 14.24 Schematic illustration of the need for a preshaped blank to machine a monolithic structure, for example, when the necessary material thickness is not available

* R. Mishra & M. Mahoney, "Friction Stir Processing," in *Friction Stir Welding & Processing*, © ASM International, 2007, pp 329-350

Materials Produced by FS

- Superplasticity
  - *Selective superplastic forming*
  - *Superplastic forming of thick sheets*
  - *One-step processing for superplasticity from*
  - *Cast sheet or hot-pressed powder metallurgy sheet*





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Materials Produced by FS

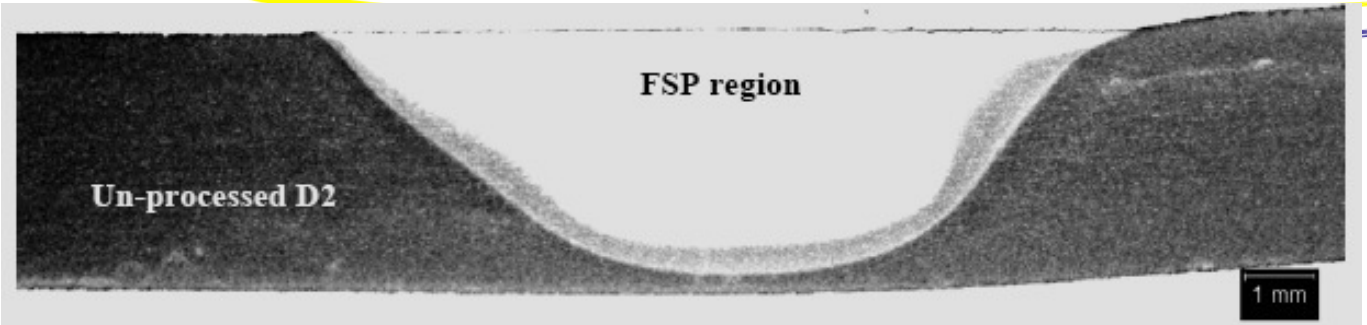


Figure 6: Photomacrograph of FSP D2 steel etched with 10% Nitric acid in methanol.

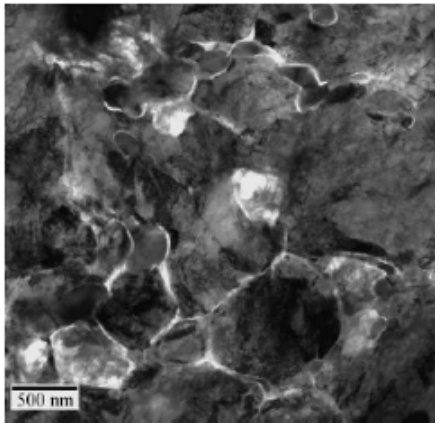


Figure 4: Transmission electron micrograph of FSP D2 at 250 RPM and 4 in/min showing typical grain sizes of 500nm.

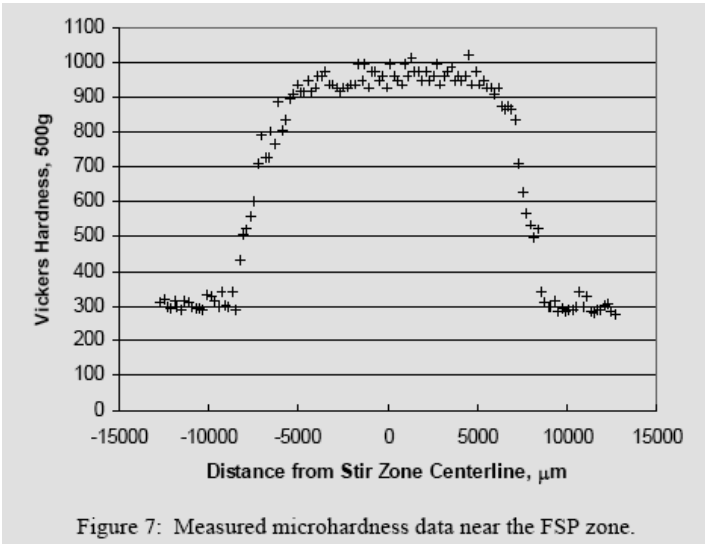
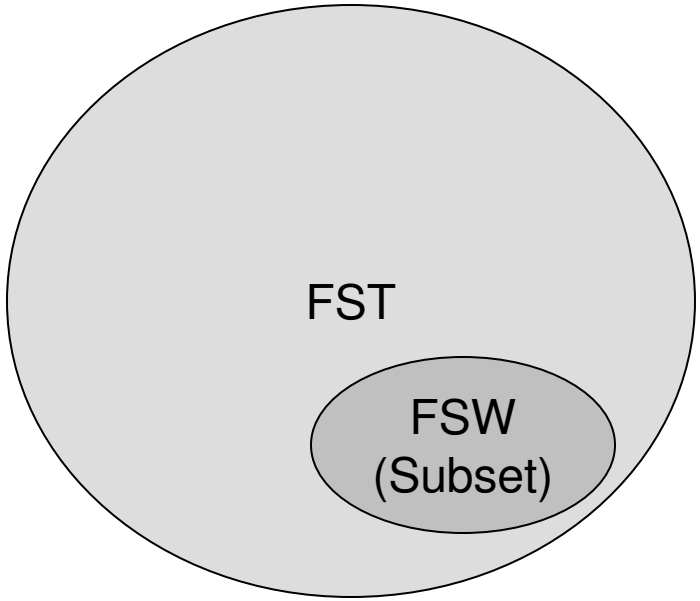


Figure 7: Measured microhardness data near the FSP zone.

Carl D. Sorensen, Tracy W. Nelson, Scott M. Packer, Charles Allen, "FRICTION STIR PROCESSING OF D2 TOOL STEEL FOR ENHANCED BLADE PERFORMANCE," TMS FSW&P Symposium, February 2007

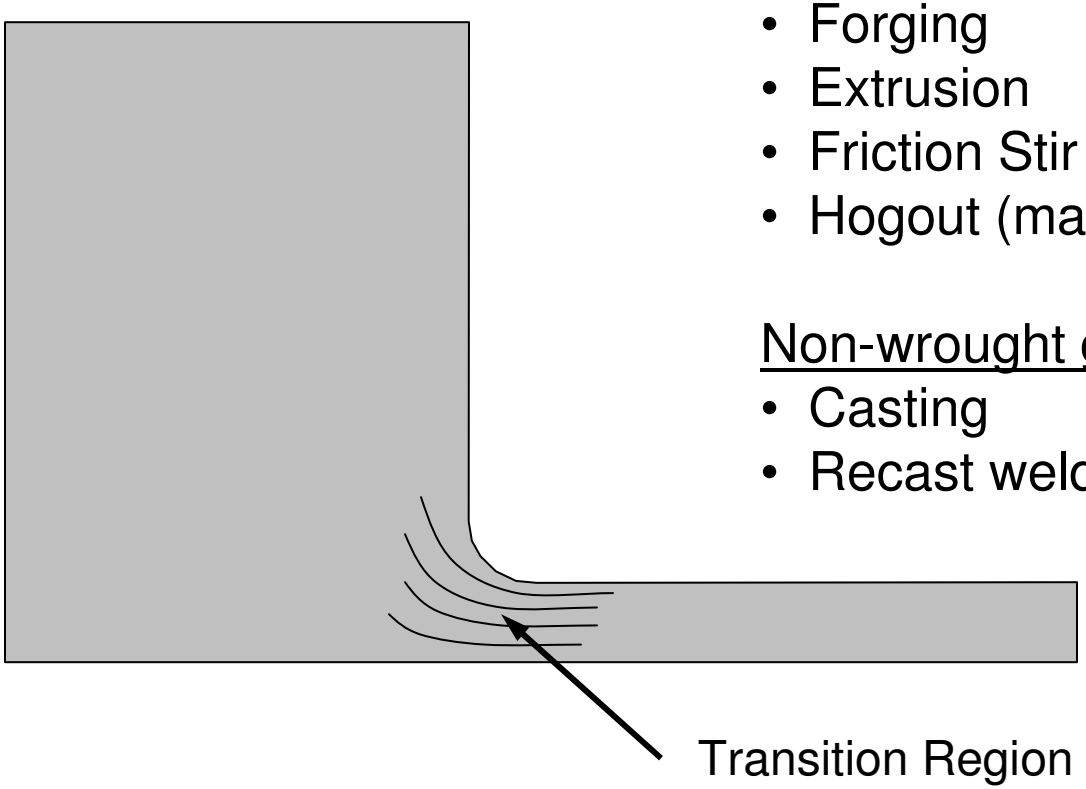
Friction Stir Technologies

- A Family of Technologies
  - FS Additive Manufacturing
  - FS Composites
  - FS Forging
  - FS Processing
  - FS Repair
  - FS Spot Welding
  - FS Surface Modification
  - FS Tailored Blanks & Manufacturing Assist
  - FS Welding / Joining (… obtw, you can join with it!)
- **FST Produce Wrought Microstructure**
  - **Sub-solidus metalworking operations**
  - **Promotes fine, equiaxed (recrystallized) grain structure**



Friction Stir Technologies

Multiple possible/practical processing paths exist for producing general shapes



<u>Wrought Metal Grain Flow</u>

- Forging
- Extrusion
- Friction Stir
- Hogout (machining) from Plate

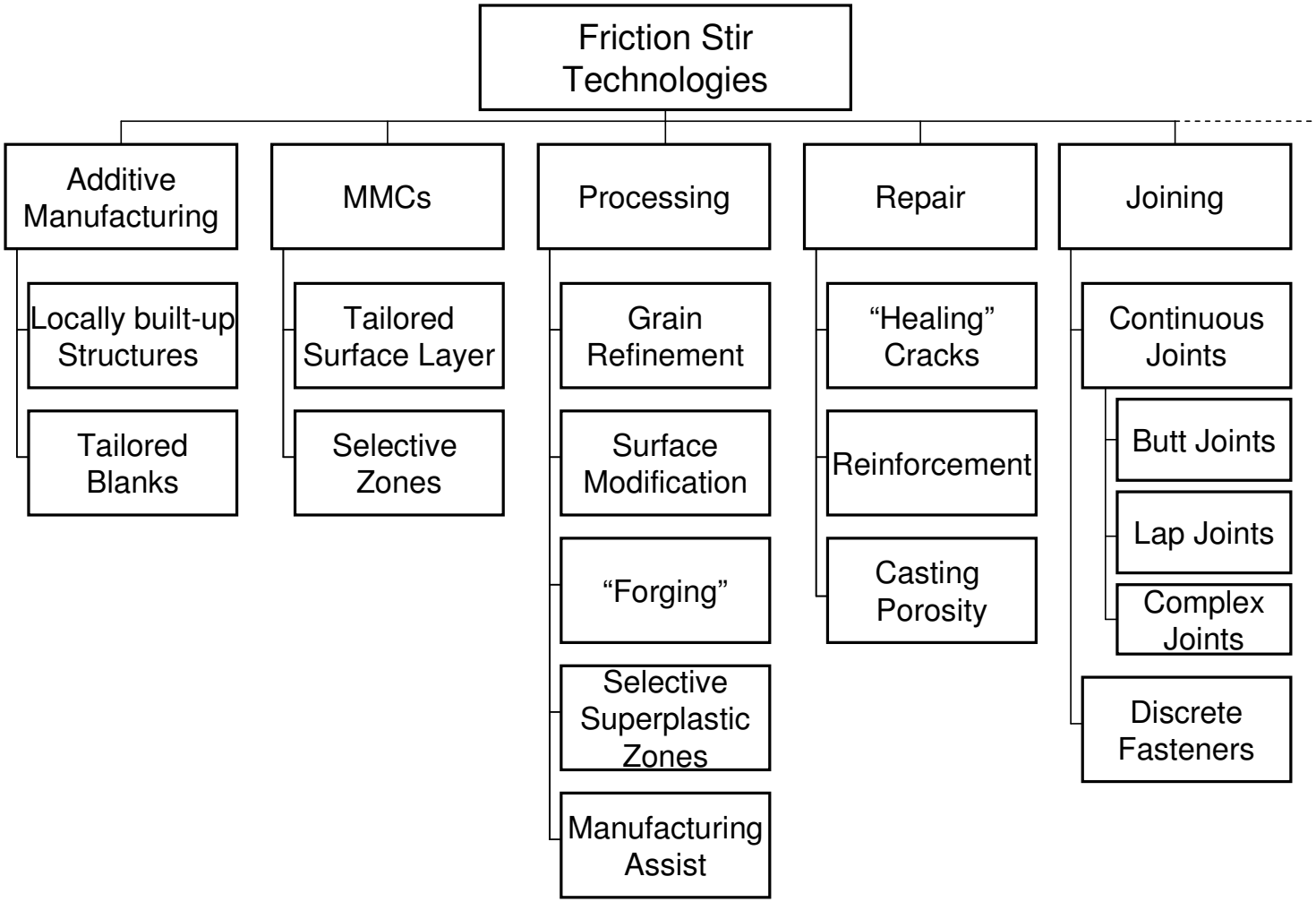
<u>Non-wrought grain structure</u>

- Casting
- Recast welded zone

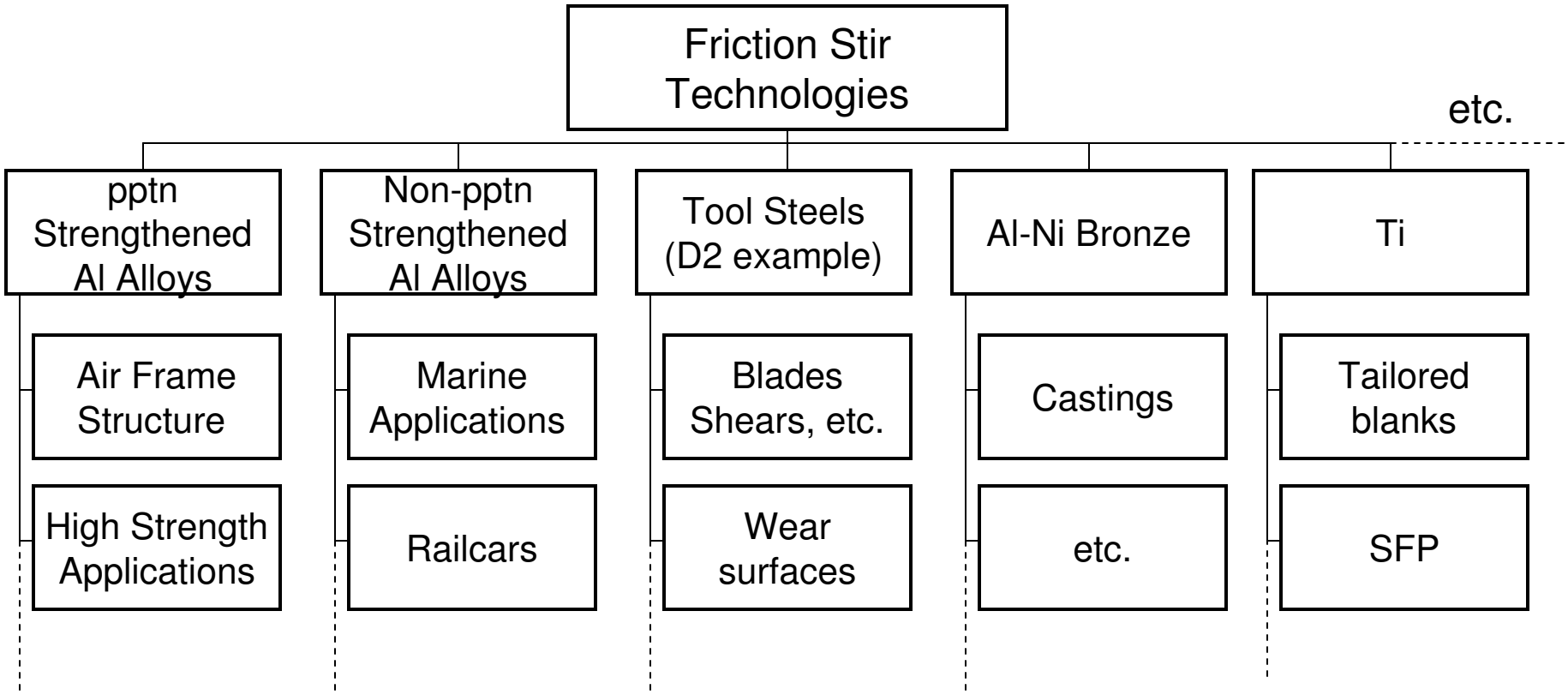
Outline

- SAE Material Specs/Stds for FS Materials
  - SAE Committee Coordination
  - Material Specifications Roadmap Approach
  - **Roadmap**

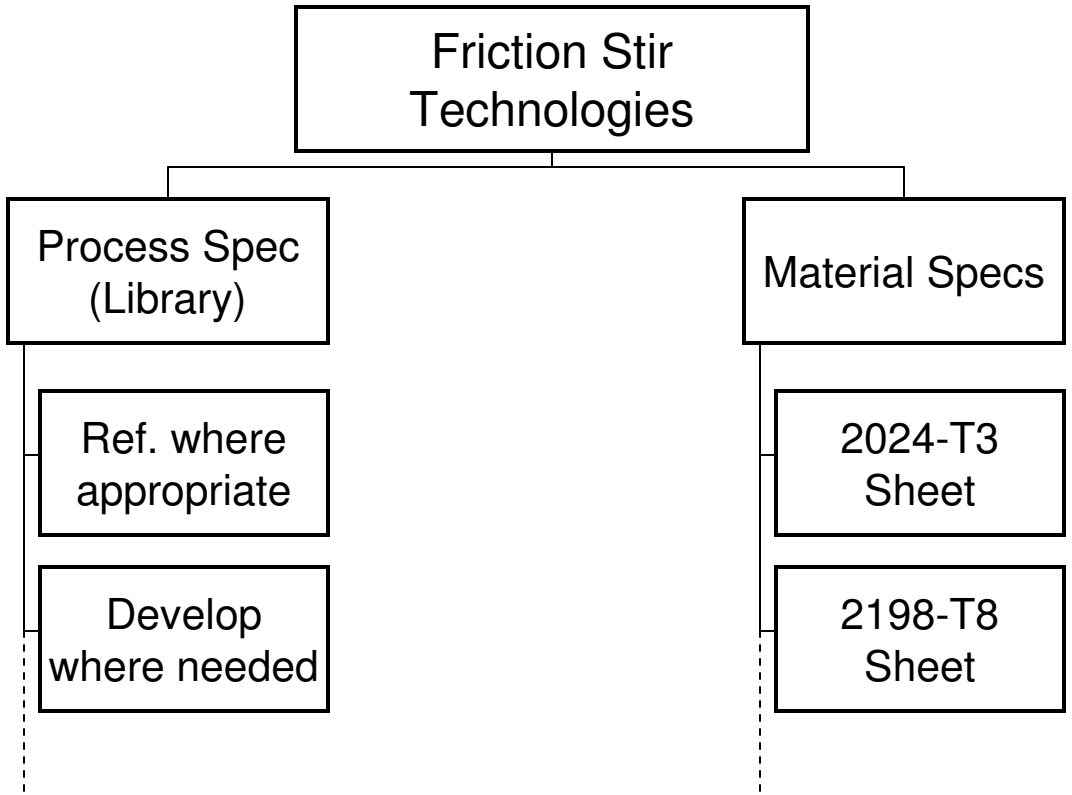
Road Map Development



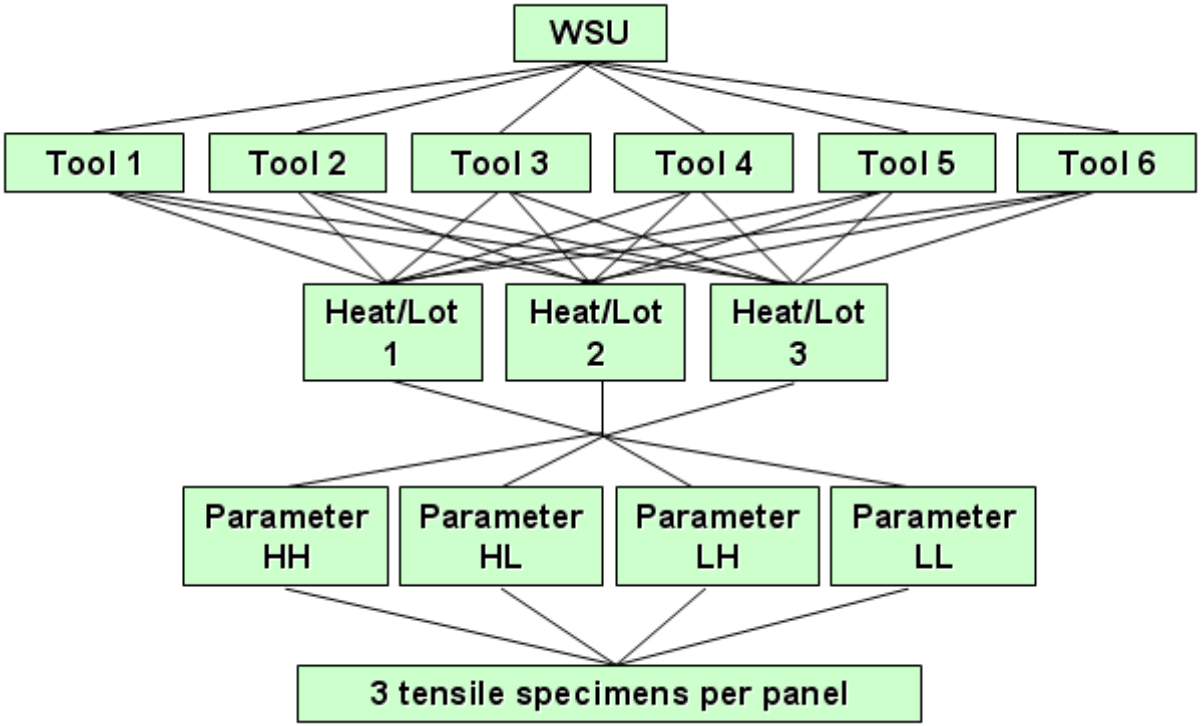
Road Map Development



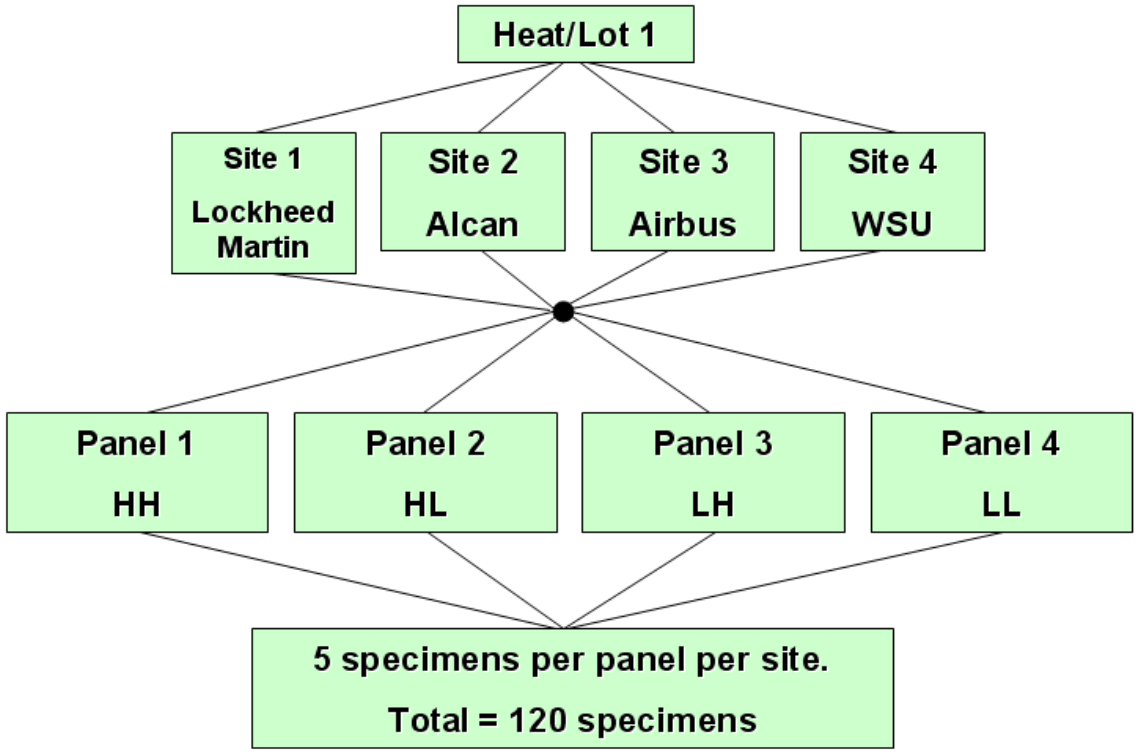
Road Map Development



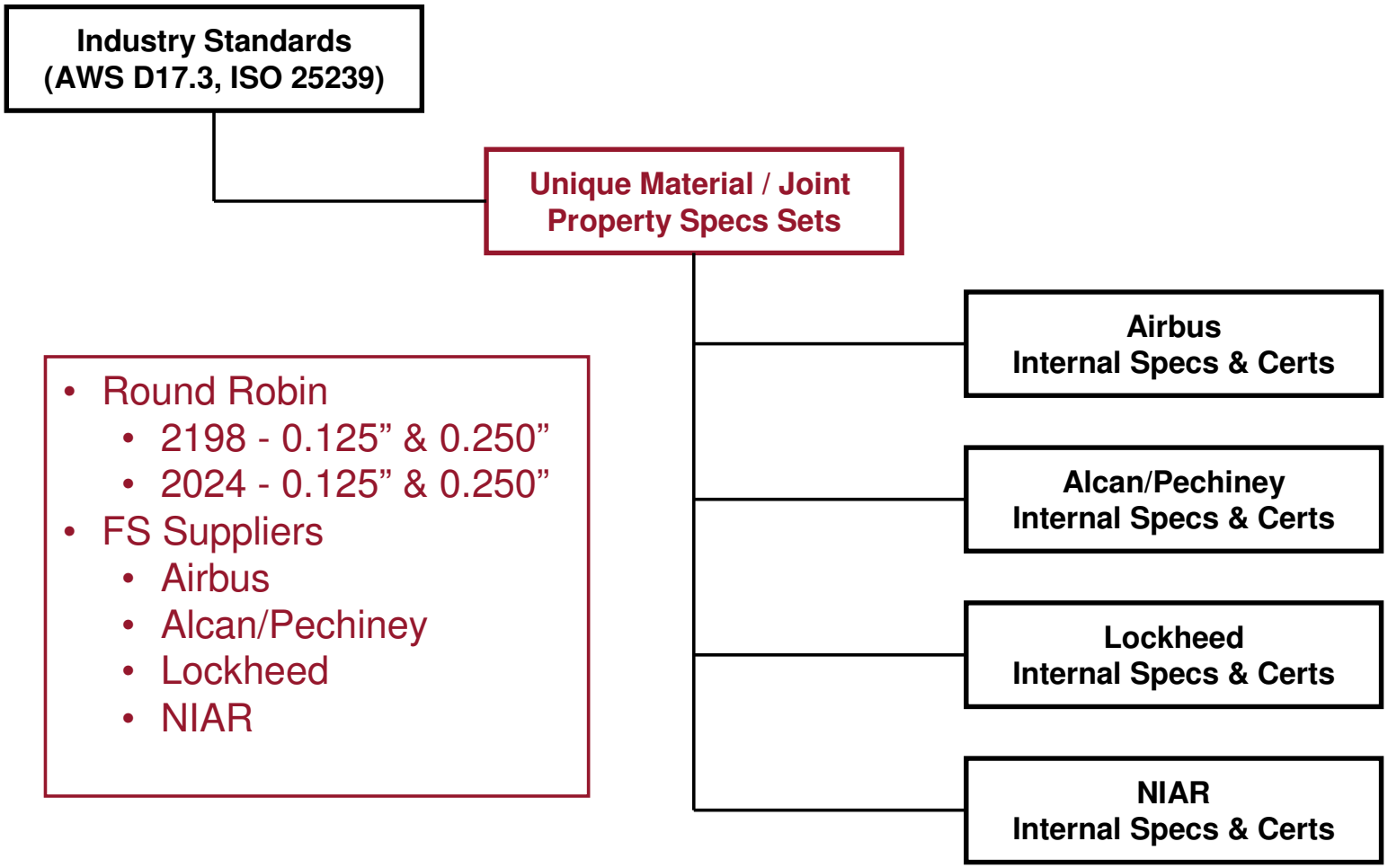
Path Independence Investigation Variability Factors



MMPDS Round Robin



MMPDS Round Robin



- Round Robin
  - 2198 - 0.125” & 0.250”
  - 2024 - 0.125” & 0.250”
- FS Suppliers
  - Airbus
  - Alcan/Pechiney
  - Lockheed
  - NIAR

Performance Specs & Standards

Situation

- A gap exists between industry specifications and supplier in-house specifications

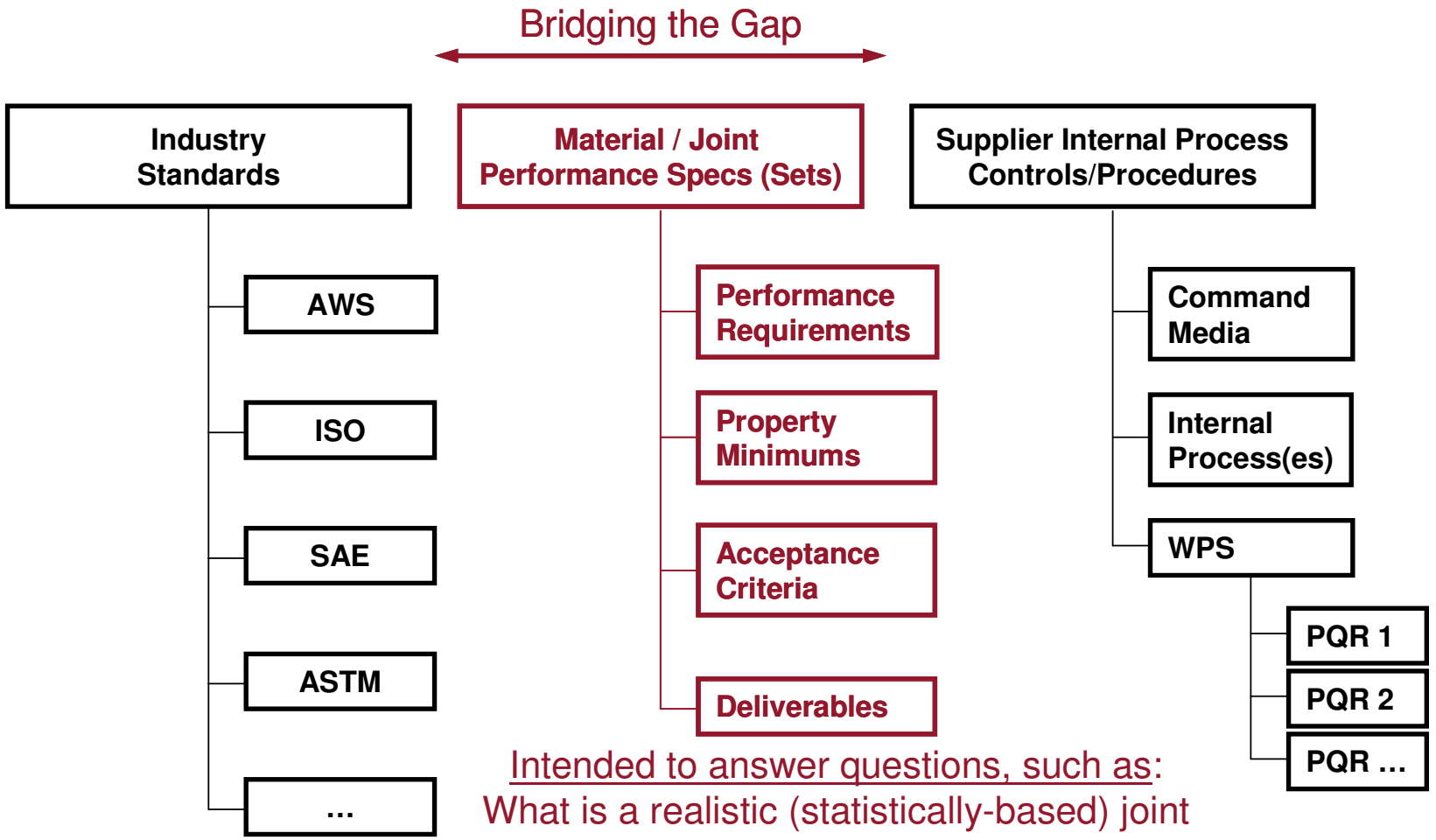
Target

- Bridge the gap by establishing sets of material performance specifications for selected alloy families and gage ranges

Proposal

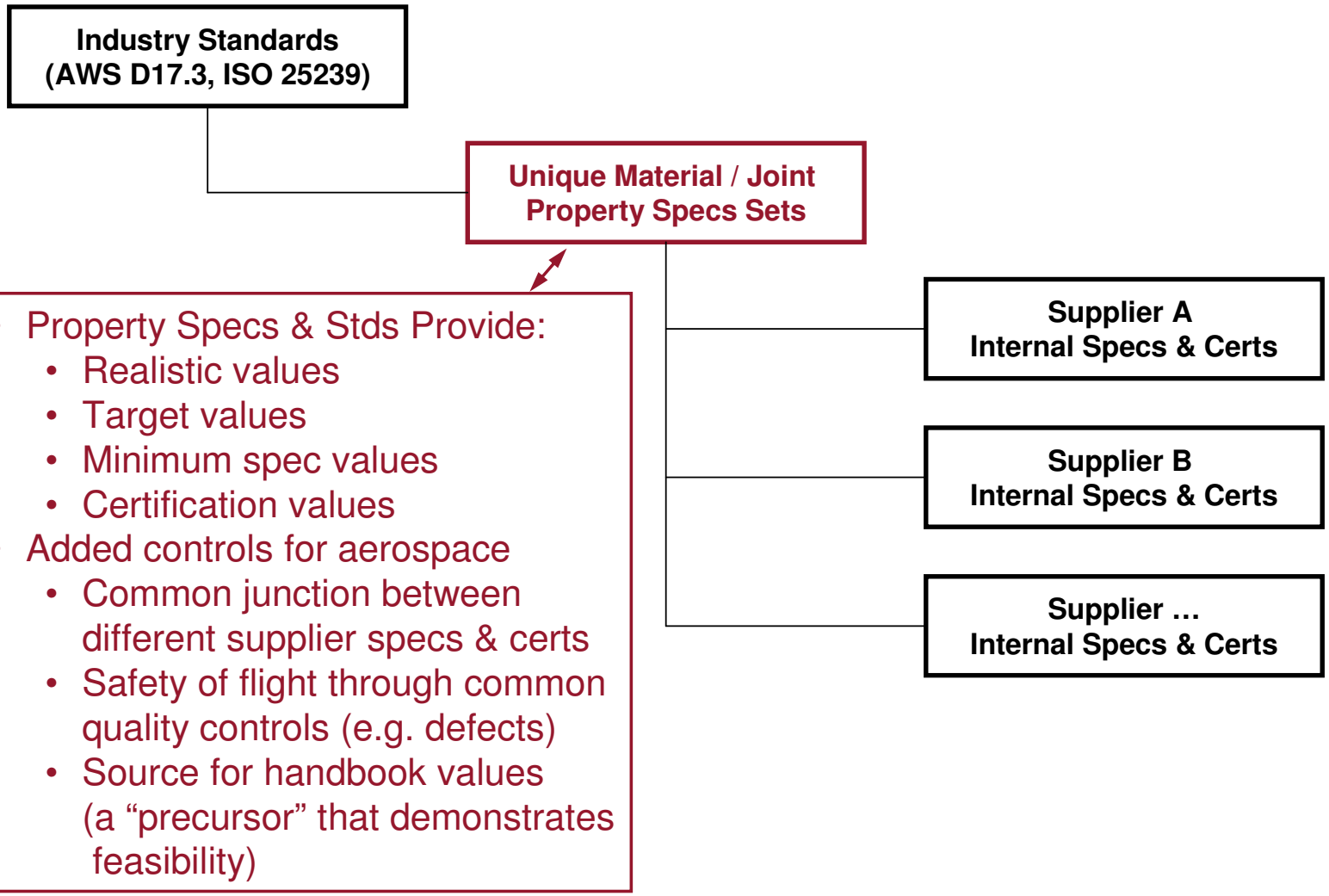
- Develop sets of performance/property specifications
  - Example: 2024-T3 sheet
  - Superimpose thermomechanical (TM) operation on prior TM history
  - Start with material that is governed by an AMS or other suitable standard material

Performance Specs & Standards

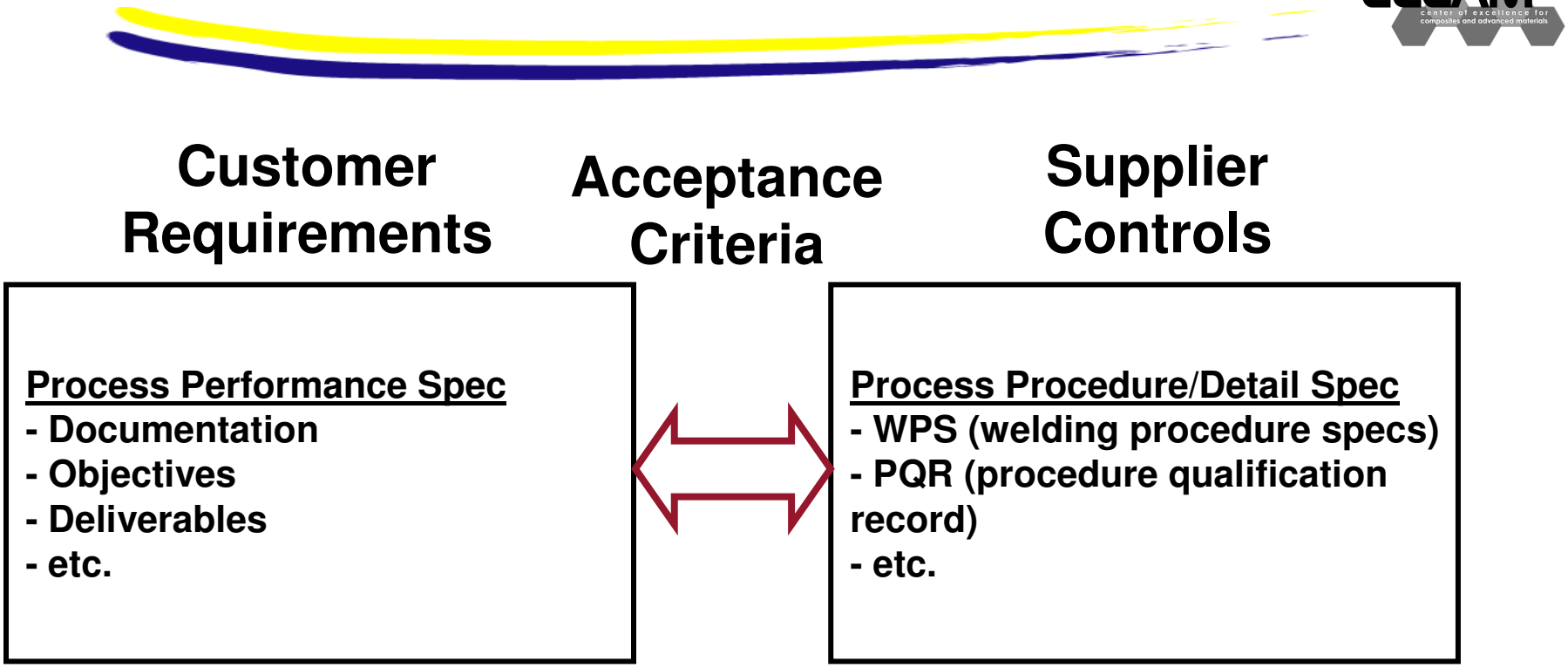


Intended to answer questions, such as:
What is a realistic (statistically-based) joint strength for a particular alloy & configuration?

Properties Specs & Standards



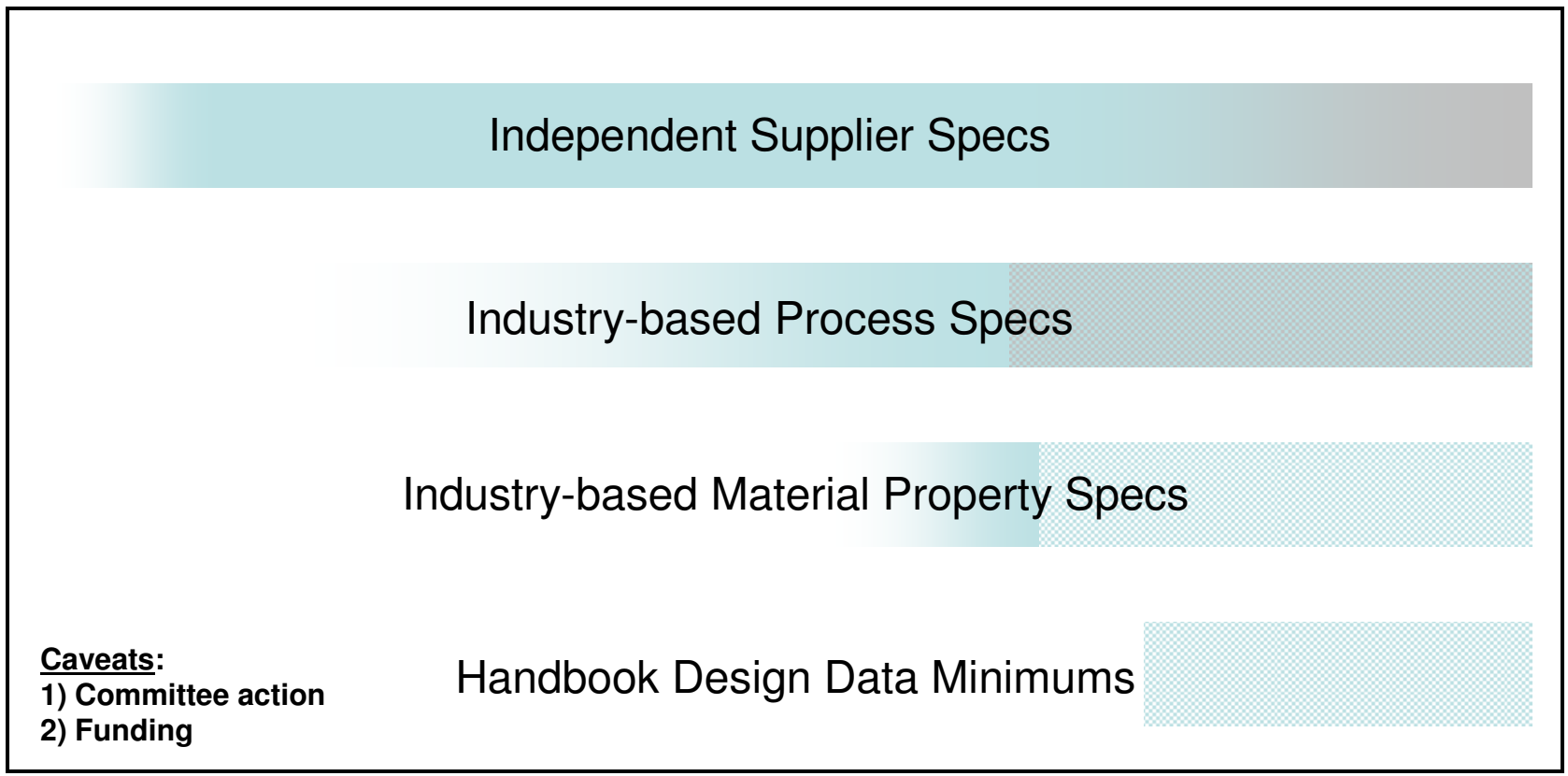
Properties Specs & Standards



Foundation:
Industry Specs (AWS, ISO, etc.)
MMPDS* methodology/coordination

*Metallic Materials Properties Development & Standardization (formerly MIL-HDBK-5)

Timeline


Independent Supplier Specs
Industry-based Process Specs
Industry-based Material Property Specs
Handbook Design Data Minimums
Caveats:
1) Committee action
2) Funding
1990
1992
1994
1996
1998
2000
2002
2004
2008
2010
2012
2014
2016
2018

Summary & Conclusions

Existing

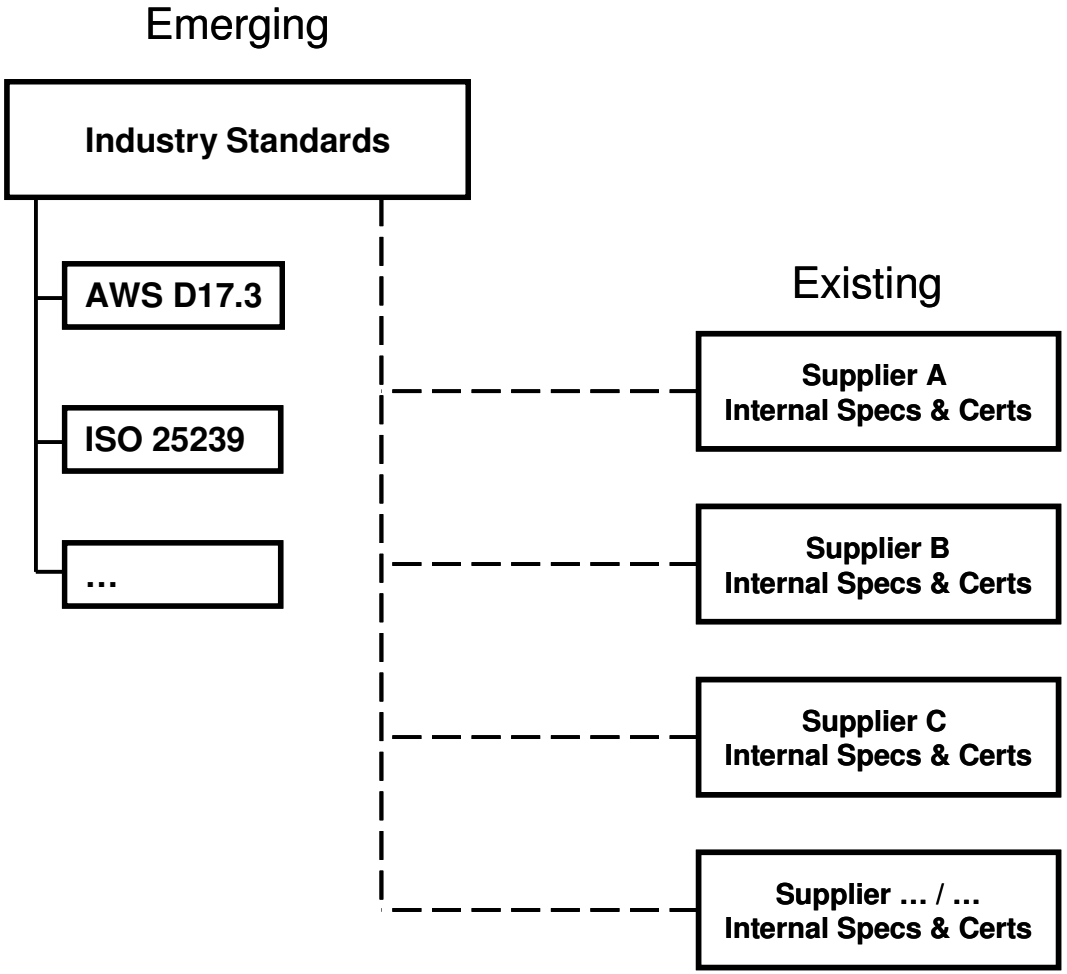
Supplier A
Internal Specs & Certs

Supplier B
Internal Specs & Certs

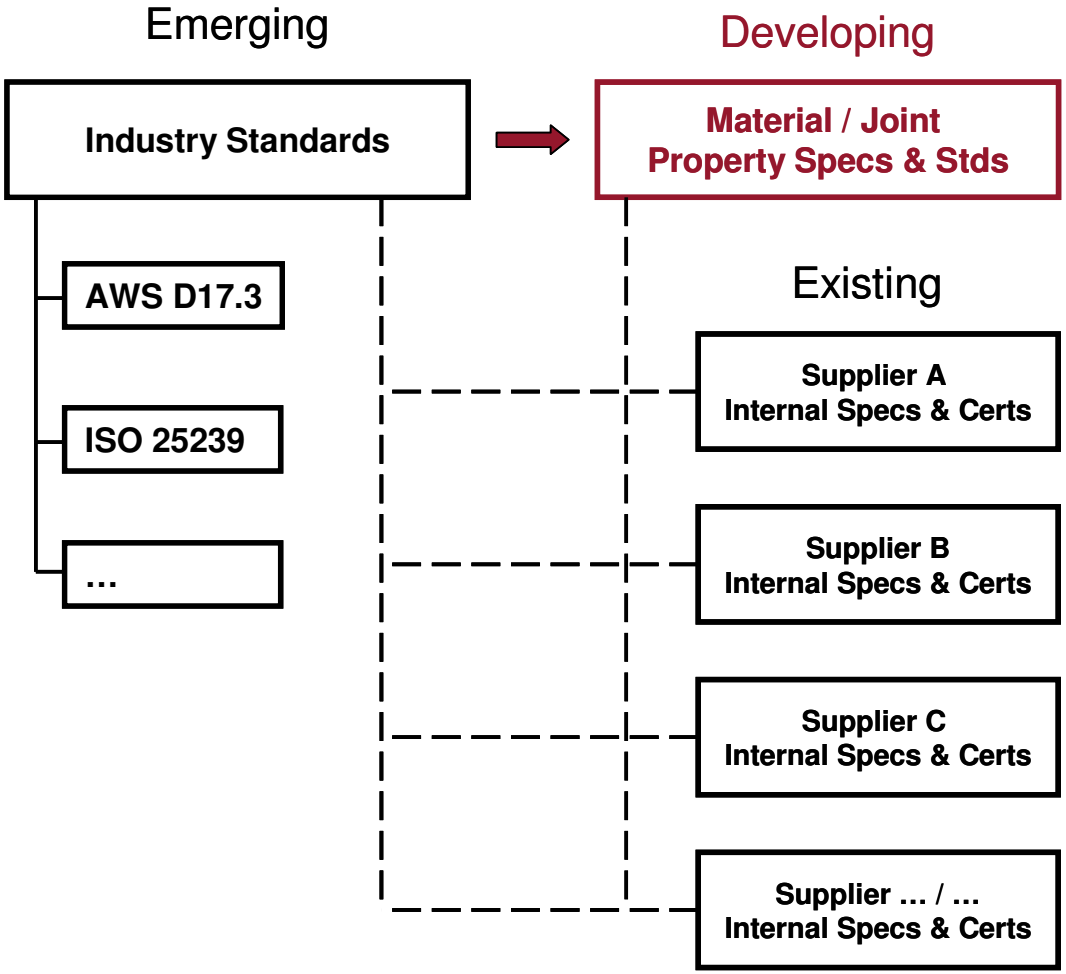
Supplier C
Internal Specs & Certs

Supplier … / …
Internal Specs & Certs

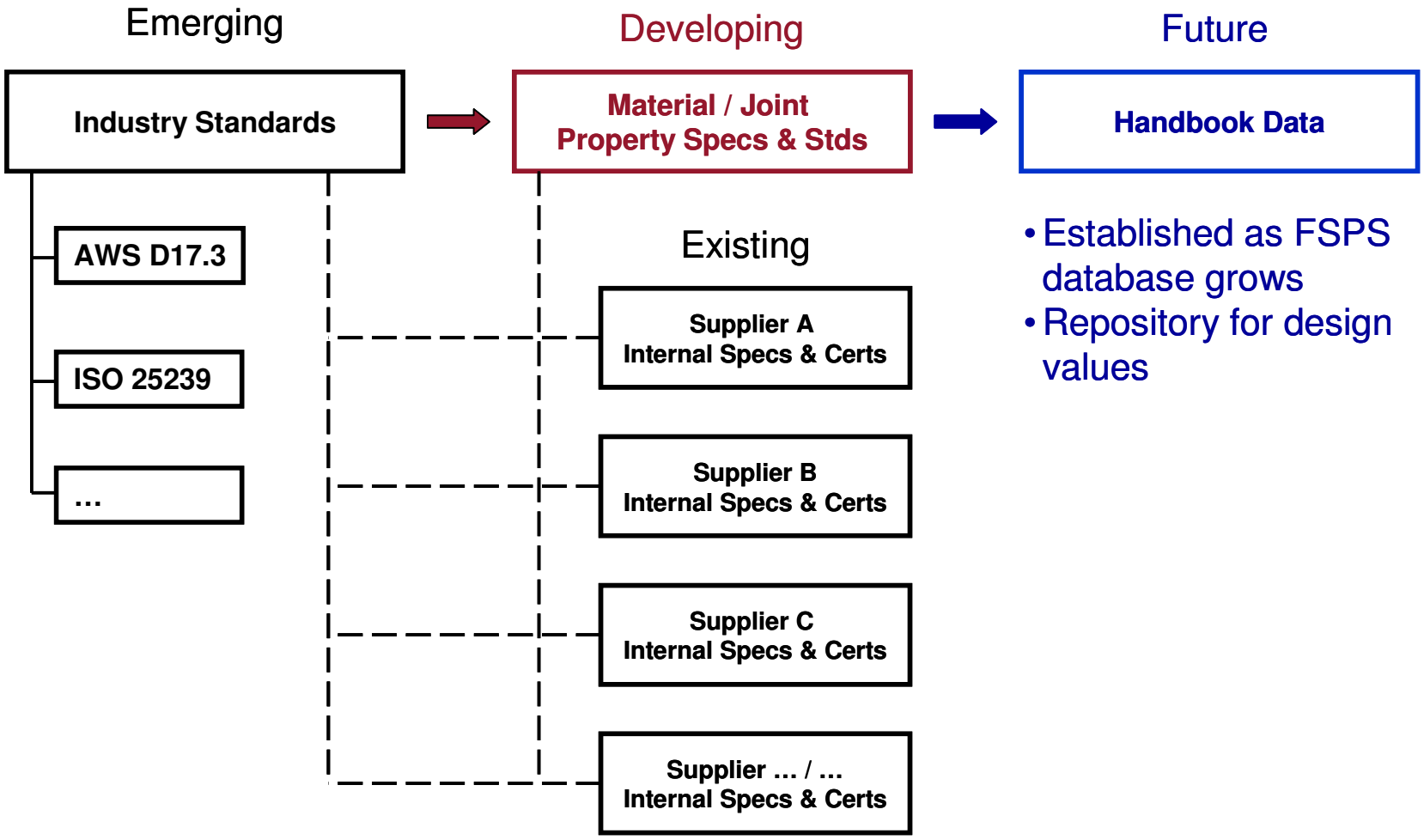
Summary & Conclusions



Summary & Conclusions



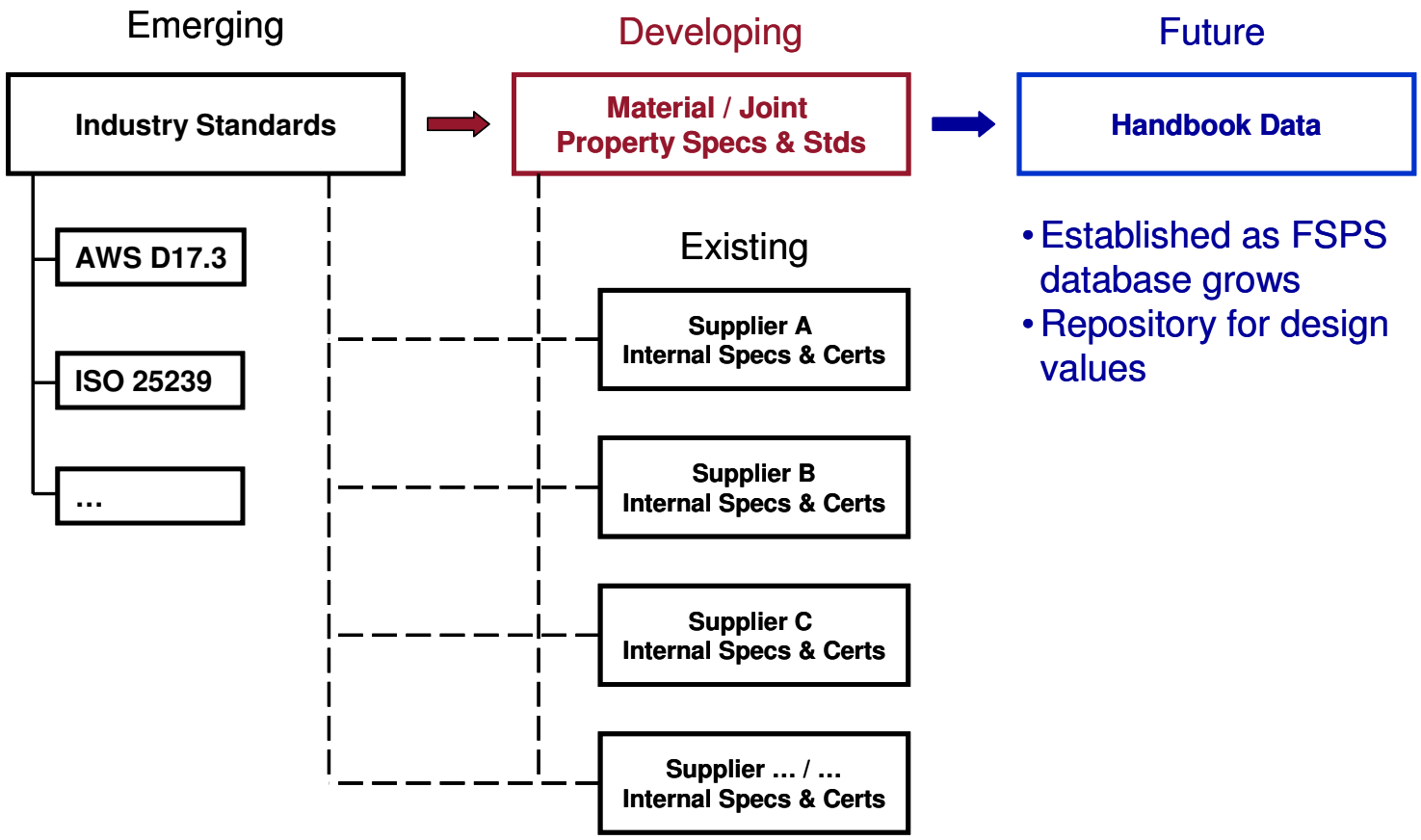
Summary & Conclusions



- Established as FSPS database grows
- Repository for design values

Summary & Conclusions

"Design for Manufacturing" Analogy



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