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
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Outline

• SAE Material Specs/Stdgs for FS Materials
  – SAE Committee Coordination
  – Material Specifications Roadmap Approach
  – Draft Roadmap
SAE Material Specs/Stdss

• 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)
• 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
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
• 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)
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/Standards 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


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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

![Diagram of FS Integral Insert](image1)

![Diagram of FS Integral Liner](image2)

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Unique Product Forms

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

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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
• 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
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Joint Construction

Installed Fastener Joints

Insert fastener through mechanical drilling and compression

Integral Fasteners/Joints

Insert fastener through mechanical stirring

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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


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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%.

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

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

Materials Produced by FS

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

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

Figure 7: Measured microhardness data near the FSP zone.

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
Multiple possible/practical processing paths exist for producing general shapes

**Wrought Metal Grain Flow**
- Forging
- Extrusion
- Friction Stir
- Hogout (machining) from Plate

**Non-wrought grain structure**
- Casting
- Recast welded zone

Transition Region
Outline

• SAE Material Specs/Stds for FS Materials
  – SAE Committee Coordination
  – Material Specifications Roadmap Approach
  – Roadmap
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Road Map Development

Friction Stir Technologies

Additive Manufacturing
- Locally built-up Structures
- Tailored Blanks

MMCs
- Tailored Surfacing Layer
- Selective Zones

Processing
- Grain Refinement
- Surface Modification
- “Forging”
- Selective Superplastic Zones
- Manufacturing Assist

Repair
- “Healing” Cracks
- Reinforcement
- Casting Porosity

Joining
- Continuous Joints
- Butt Joints
- Lap Joints
- Complex Joints
- Discrete Fasteners
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Road Map Development

Friction Stir Technologies

- pptn Strengthened Al Alloys
  - Air Frame Structure
  - High Strength Applications
- Non-pptn Strengthened Al Alloys
  - Marine Applications
  - Railcars
- Tool Steels (D2 example)
  - Blades Shears, etc.
  - Wear surfaces
- Al-Ni Bronze
  - Castings
  - etc.
- Ti
  - Tailored blanks
  - SFP

etc.
Road Map Development

Friction Stir Technologies

Process Spec (Library)
- Ref. where appropriate
- Develop where needed

Material Specs
- 2024-T3 Sheet
- 2198-T8 Sheet

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Path Independence Investigation
Variability Factors

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MMPDS Round Robin

Heat/Lot 1
  / 
 /   
Site 1 Site 2 Site 3 Site 4
  |   |   |   |
Lockheed Alcan Airbus WSU
  |
  |
Panel 1 Panel 2 Panel 3 Panel 4
  |   |   |   |
HH   HL   LH   LL

5 specimens per panel per site.
Total = 120 specimens
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MMPDS Round Robin

Industry Standards
(AWS D17.3, ISO 25239)

Unique Material / Joint Property Specs Sets

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

Airbus
Internal Specs & Certs

Alcan/Pechiney
Internal Specs & Certs

Lockheed
Internal Specs & Certs

NIAR
Internal Specs & Certs
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
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Performance Specs & Standards

Bridging the Gap

Industry Standards
  - AWS
  - ISO
  - SAE
  - ASTM
  - ...

Material / Joint Performance Specs (Sets)
  - Performance Requirements
  - Property Minimums
  - Acceptance Criteria
  - Deliverables

Supplier Internal Process Controls/Procedures
  - Command Media
  - Internal Process(es)
  - WPS
    - PQR 1
    - PQR 2
    - PQR ...

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

Industry Standards (AWS D17.3, ISO 25239)

Unique Material / Joint Property Specs Sets

- Property Specs & Stds Provide:
  - Realistic values
  - Target values
  - Minimum spec values
  - Certification values
- Added controls for aerospace
  - Common junction between different supplier specs & certs
  - Safety of flight through common quality controls (e.g. defects)
  - Source for handbook values (a “precursor” that demonstrates feasibility)

Supplier A
Internal Specs & Certs

Supplier B
Internal Specs & Certs

Supplier ...
Internal Specs & Certs
Properties Specs & Standards

Customer Requirements

- Process Performance Spec
  - Documentation
  - Objectives
  - Deliverables
  - etc.

Acceptance Criteria

Supplier Controls

- Process Procedure/Detail Spec
  - WPS (welding procedure specs)
  - PQR (procedure qualification record)
  - etc.

Foundation:

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

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

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Timeline

Independent Supplier Specs

Industry-based Process Specs

Industry-based Material Property Specs

Handbook Design Data Minimums

Caveats:
1) Committee action
2) Funding
Summary & Conclusions

Existing

Supplier A
Internal Specs & Certs

Supplier B
Internal Specs & Certs

Supplier C
Internal Specs & Certs

Supplier … / …
Internal Specs & Certs

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Summary & Conclusions

Emerging

Industry Standards

- AWS D17.3
- ISO 25239
- ...

Existing

- Supplier A
  - Internal Specs & Certs
- Supplier B
  - Internal Specs & Certs
- Supplier C
  - Internal Specs & Certs
- Supplier ... / ...
  - Internal Specs & Certs
Summary & Conclusions

Emerging

Industry Standards

AWS D17.3

ISO 25239

...

Developing

Material / Joint Property Specs & Stds

Existing

Supplier A Internal Specs & Certs

Supplier B Internal Specs & Certs

Supplier C Internal Specs & Certs

Supplier … / … Internal Specs & Certs

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Summary & Conclusions

- Emerging Industry Standards
  - AWS D17.3
  - ISO 25239
  - ...

- Developing Material / Joint Property Specs & Stds
  - Supplier A Internal Specs & Certs
  - Supplier B Internal Specs & Certs
  - Supplier C Internal Specs & Certs
  - Supplier ... / ...

- Future Handbook Data
  - Established as FSPS database grows
  - Repository for design values

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Summary & Conclusions

“Design for Manufacturing” Analogy

Emerging
- Industry Standards
  - AWS D17.3
  - ISO 25239
  - ...

Developing
- Material / Joint Property Specs & Stds
  - Existing
    - Supplier A
      - Internal Specs & Certs
    - Supplier B
      - Internal Specs & Certs
    - Supplier C
      - Internal Specs & Certs
    - Supplier ... / ...
      - Internal Specs & Certs

Future
- Handbook Data
  - Established as FSPS database grows
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