Linear Friction Welding (LFW)
TiFab: Creation of the first Supply Chain

Titanium Europe 2016
Bertrand Flipo
Linear friction welding - bottom line

- Forging process: quick, automated, repeatable, high integrity
- Advantages: reducing material usage and time to market
- Titanium alloys: ideal for material tailoring by LFW
- TiFab consortium*: currently the only supply chain for LFW
  (*CAV; TFW; TEN; TWI)
World centre for materials joining

- Impartial
  - Non-governmental
  - Not for profit distributing
  - Independent

- Mission:
  To be extremely good at what we do, so we can help others*

  * To deliver world class services in joining materials, engineering and allied technologies to meet the needs of a global membership and its associated community

- Dedicated to materials joining
  - Over $100m R&D per year
  - Over 850 staff in 4 UK centres
  - Over 700 industrial members
  - 60 years track record
TWI - Friction and Forge Processes

- Based in Cambridge, UK
- 16 Engineers and Technicians
- 53 years of R&D in friction processes
  - One of the first in friction welding
  - Pioneered linear friction welding
  - Invented friction stir welding
Linear friction welding

High integrity, quick, automated, repeatable, self regulated, self cleaning, forging process

not Linear Friction Stir Welding
LFW real time and slow motion

Time dependant process: typically <1min regardless of volume to weld
Typical positioning: accuracy <0.10mm; repeatability <0.25mm

TWI YouTube channel:   https://www.youtube.com/user/twiltd
LFW for Ti: forged microstructure

- Hot forged microstructure
- Virtually non-existent HAZ
- Fine grained equiaxed recrystallised microstructure found at weld centreline
- Can be post weld heat treated for performance
- Parent tensile and fatigue properties can be recovered

↑ Ti-6Al-4V ↓
LFW for Ti: parent material performance

- Hot forged microstructure
- Virtually non-existent HAZ
- Fine grained equiaxed recrystallised microstructure found at weld centreline
- Can be post weld heat treated for performance
- Parent tensile and fatigue properties can be recovered
LFW: used for flight critical Ti Blisks

- Mature use: 5th gen fighters LPCs
  - Excellent power to weight ratio
  - Parts proven to outlast the engine

- Current uptake: civil engines
  - Operational efficiency
  - Environmental regulations

- Dependable process
  - Originating from Aerospace
  - Blisks have in-house qualifications
LFW for manufacturing

- **Agile**
  - Fast, adaptable, forged
  - Automated, reproducible

- **Implementable:**
  - Changing the material input format
  - Finishing operations remain identical

- **Cost effective**
  - Time dependent process improving part throughput / time to market
  - Can make use of standard plates
    - Stabilises part cost at material input
    - Makes better use of leaner material stocks

- Process showing high potential beyond cost savings
LFW: design freedoms beyond savings

- Material tailoring
  - Strategic placement of dissimilar alloys
  - Best suited material / orientation for part purpose
  - Costs control by material selection

- Nested performance
  - Combine LFW with high-end processes (forging, AM...)

- Monolithic structures
  - Part count reduction
  - Simplified assembly & QA
  - Simplified maintenance

Potential Example:

Ti6246 (temperature)
Ti64 (economical)
New design freedoms with LFW: last iteration of smart manufacturing

- Design freedoms
  - Everybody on board
- Materials tailoring
  - Material Engineers
- Time-to-market
  - Production engineers
- Buy-to-fly
  - Accountants
- Manufacture anything at all
  - Supply chain
Bridging the gap to industrialisation

TiFab: an Innovate UK project

- Ti-6Al-4V Joint performance data
  - LFW parametric conditions and heat treatment
  - Static and fatigue loading

- In-process quality monitoring and tooling design
  - Flagging of non conformant behaviour
  - Tooling modular, scalable

- Demonstrator
  - Survey of LFW part candidates and potential savings
  - Creation of an aero structure demonstrator

- Setup of a supply chain for LFW parts
  - EU based
  - From plate to part
Creating the missing link
LFW supply chain

- Setup of a UK based supply chain for LFW parts
  - Tier 1 OEM suppliers  CAV – project lead
  - LFW manufacturer  Thompson Friction Welding
  - Business analyst  Ten Solutions
  - LFW process Pioneer  TWI

- “Virtual” production cell
  - Equipment in various parts of the UK
  - Handling of first articles and low production rates
  - ISO 9001 and EN/AS 9100 QA
Stimulating enthusiasm: LFW demonstrator

- Collaboration with aerospace OEMs
  - Survey of 100s LFW candidates
  - Strategy for LFW blanks
  - Down selection
  - Business case

- Demonstrator design
  - Inspired from OEM parts
  - As welded and finished sides

- Tooling modular, scalable
  - One demonstrator
  - made on several machines
  - Process QA monitoring in place
Assuring to succeed: monitoring and analysis

- TWI core activity: behaviour of the welding processes
  - 1978: TWI patented quality monitoring for friction welding

- Evidences supporting the welding operation
  - Unobtrusive addition of sensors
  - Very high sampling rate
  - Automated analysis and reporting

- Adaptable quality control tools
  - Statistical process control
  - Continuous process improvement

- Transferable to other machines
  - Communicating (Industry 4.0)
Disclosing joint performance: welding conditions

- Process window and welding conditions identified for Ti-6Al-4V Grade 5 AMS4911, 25mm/1in thick plate

- General terms
  - Friction and forge above 40MPa
  - Amplitude and frequency combination above 300 mm/s
  - Burn off, stick out, etc. considered in relation with geometry

- Weld made in atmospheric conditions: **no shielding**

- Post weld heat treatment
  - Industry standards for stress relief, full annealing, solution heat treatment and aging
  - Fine tuning to preferred conditions
Disclosing joint performance: static and fatigue

- Static loading (mixed zone cross weld)
  - As welded specimen: identical to parent material
  - PWHT specimen: identical to parent material
  - No failure at the weld centreline in both cases

- Fatigue alternated loading (loaded at weld centreline)
  - As welded specimen: ≈50% of parent in HCF & LCF, low Δ
  - PWHT specimen: currently being assessed – very promising
  - Results unmatched in literature

- Parts designed for static loading could be made simply

- Full set of figures available from TiFab team
Anthony McAndrew
Contaminant removal in Ti6Al4V
- 1st publication: 2013
- 2nd publication: 2014
- Thesis: 2015

Lucie Lee
Novel industrial applications
- 1st publication: 2016
- 2nd publication: 2017
- Thesis: 2018
Biennial International LFW Symposium

- Leading LFW event worldwide
- Focus on LFW developments
- Presentations by field experts

Meet
- Research teams
- Academia
- Suppliers
- End Users

Contact: Richard Freeman, Industry Sector Manager, Aerospace. richard.freeman@twi.co.uk
Linear Friction Welding - Bottom Line

- Forging process: quick, automated, repeatable, high integrity
- Advantages: reducing material usage and time to market
- Titanium alloys: ideal for material tailoring by LFW
- TiFab consortium*: currently the only supply chain for LFW
  (*CAV; TFW; TEN; TWI)
Martin Wood

TiFab Consortium lead
Innovate UK
CAV Advanced Technologies

+44(0)1207 593543
m.wood@cav-at.com
www.nearnetshape.co.uk

Bertrand Flipo

Friction and Forge Processes Joining Group
TWI Ltd

+44 (0)1223 899 000
bertrand.flipo@twi.co.uk
www.twi-global.com