

Linear Friction Welding (LFW)

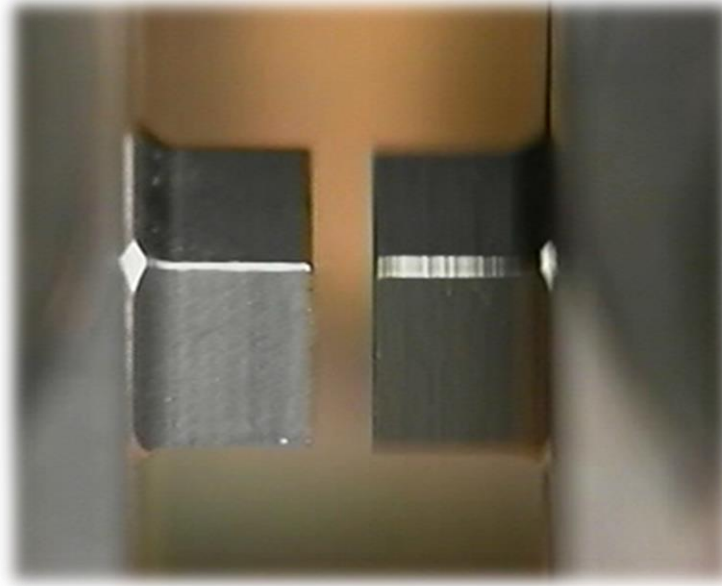
TiFab: Creation of the first Supply Chain

Titanium Europe 2016
Bertrand Flipo

Materials Joining and Engineering Technologies

A faint, stylized graphic of a globe is positioned in the bottom right corner of the slide. It shows the outlines of continents and latitude/longitude lines, with a focus on the European and African regions.

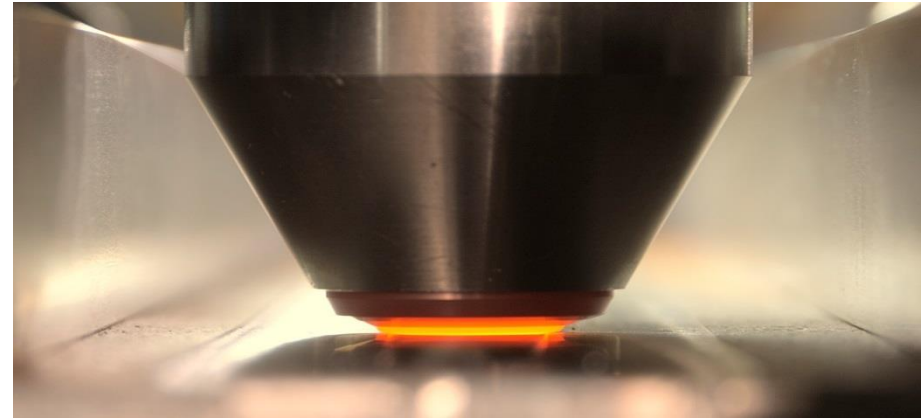
Linear friction welding - bottom line



- 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

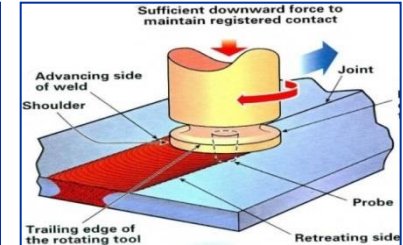
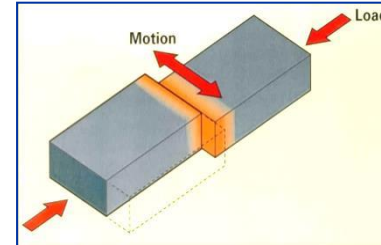
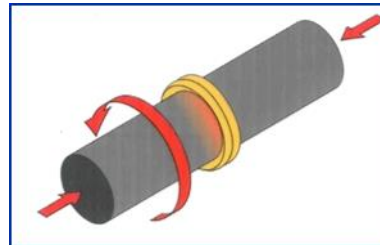
- Impartial
 - Non-governmental
 - Not for profit distributing
 - Independent
- Mission:
To be extremely good at what we do, so we can help others*
 - * To deliver world class services in joining materials, engineering and allied technologies to meet the needs of a global membership and its associated 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

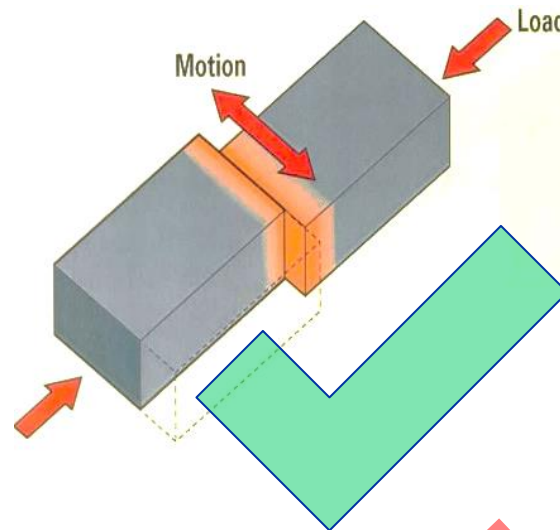


- Based in Cambridge, UK
- 16 Engineers and Technicians
- 53 years of R&D in friction processes
 - One of the first in friction welding
 - Pioneered linear friction welding
 - Invented friction stir welding



Linear friction welding

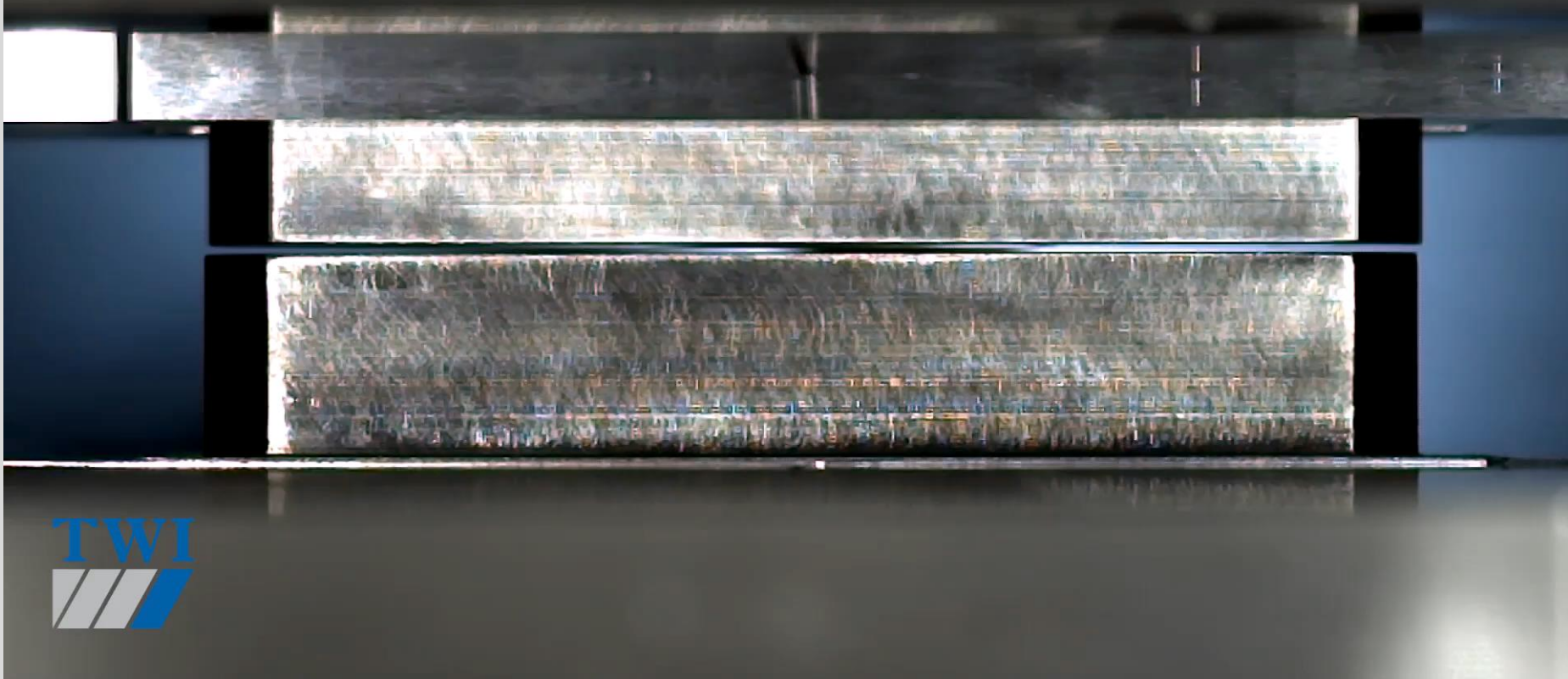
High integrity, quick, automated, repeatable, self regulated, self cleaning, forging process



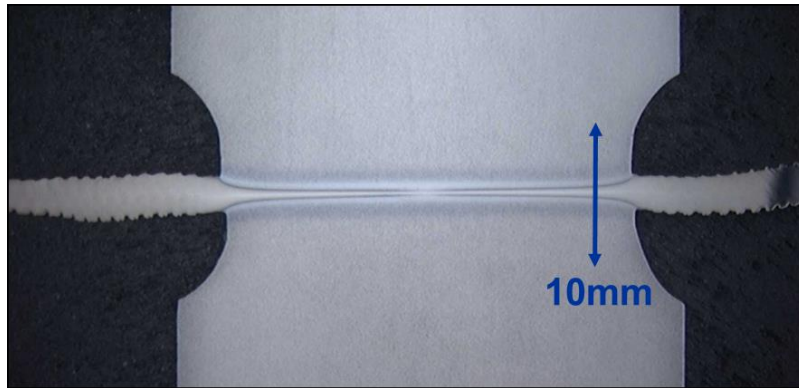
not Linear Friction ~~Stir~~ Welding

LFW real time and slow motion

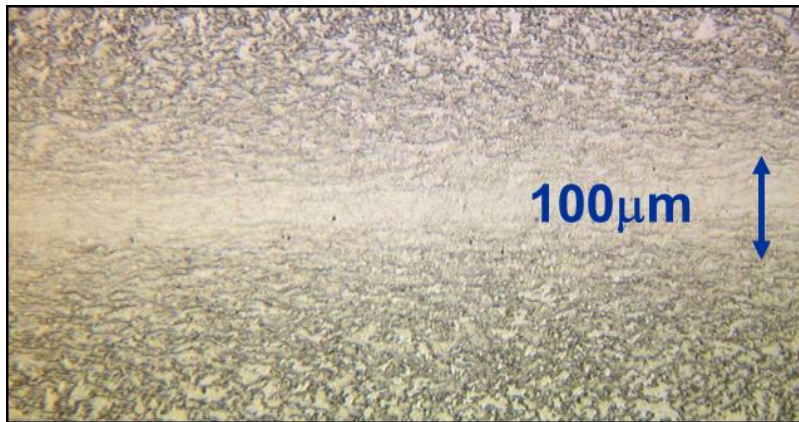
Time dependant process: typically <1min regardless of volume to weld
Typical positioning: accuracy <0.10mm; repeatability <0.25mm



LFW for Ti: forged microstructure

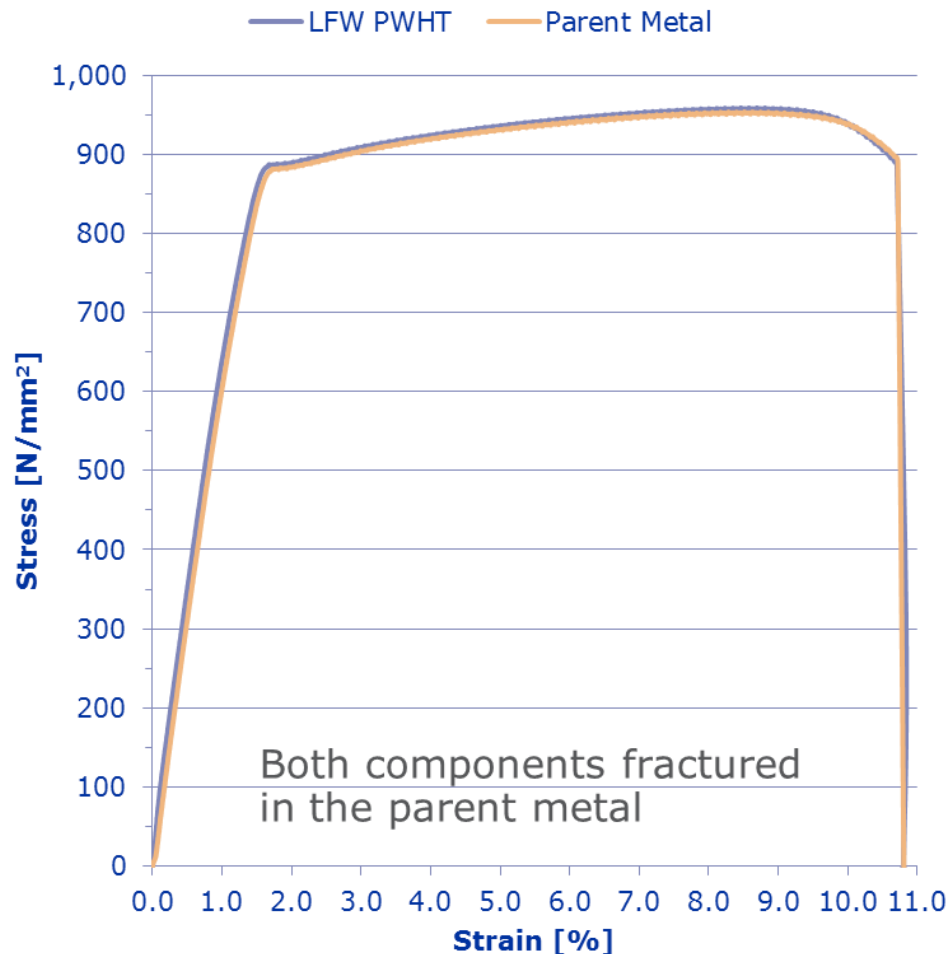


↑ Ti-6Al-4V ↓



- 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

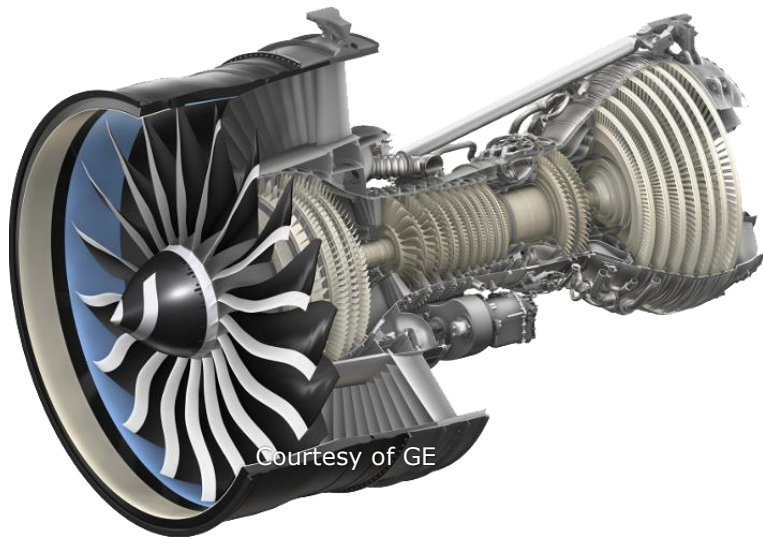
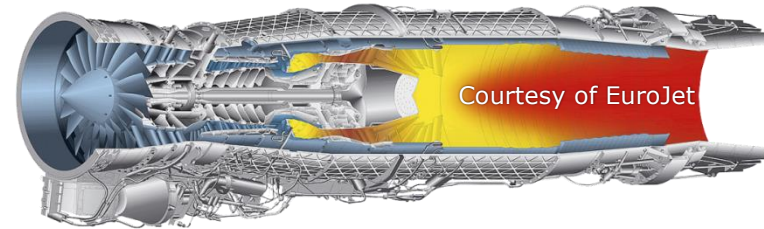
LFW for Ti: parent material performance



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LFW: used for flight critical Ti Blisks

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

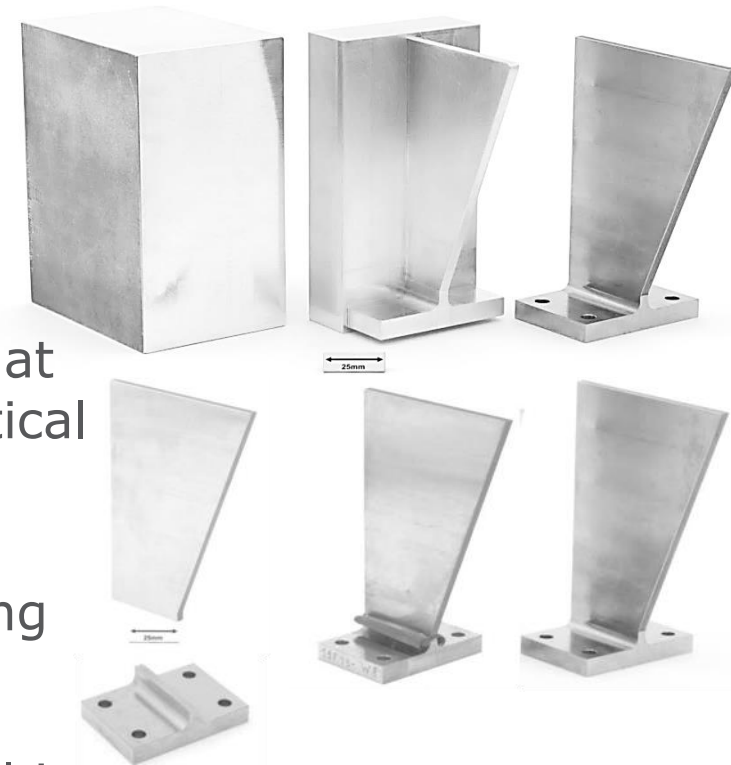


- Current uptake: civil engines
 - Operational efficiency
 - Environmental regulations

- Dependable process
 - Originating from Aerospace
 - Blisks have in-house qualifications



- 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:

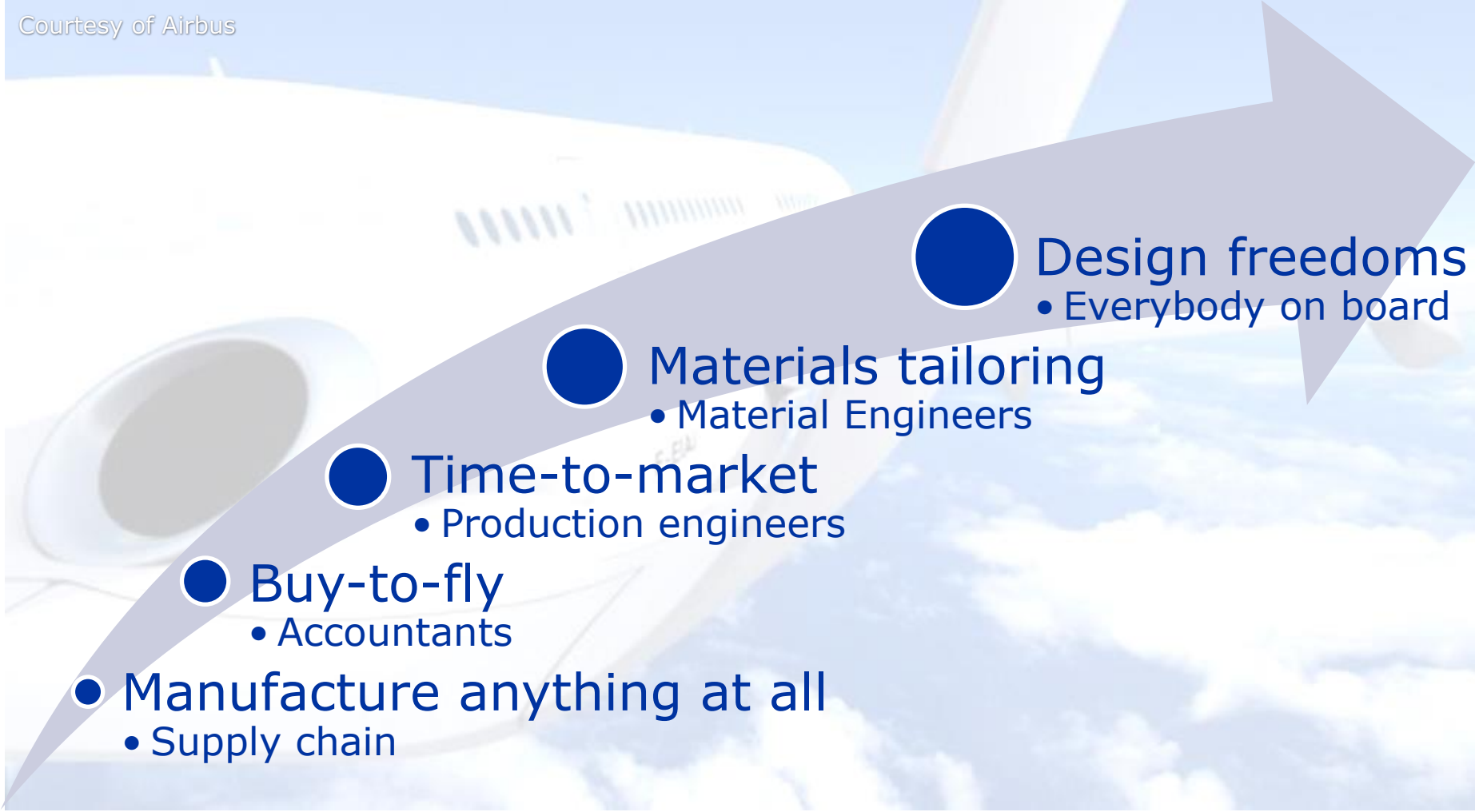
Ti6246 →
(temperature)

Ti64 →
(economical)



New design freedoms with LFW: last iteration of smart manufacturing

Courtesy of Airbus

A large, light blue arrow points from the bottom-left towards the top-right, passing over a background image of an Airbus A380 aircraft in flight. Along the arrow, five blue circles are placed, each corresponding to a design freedom. The text for each freedom is in blue, with sub-points in a smaller blue font.

● 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

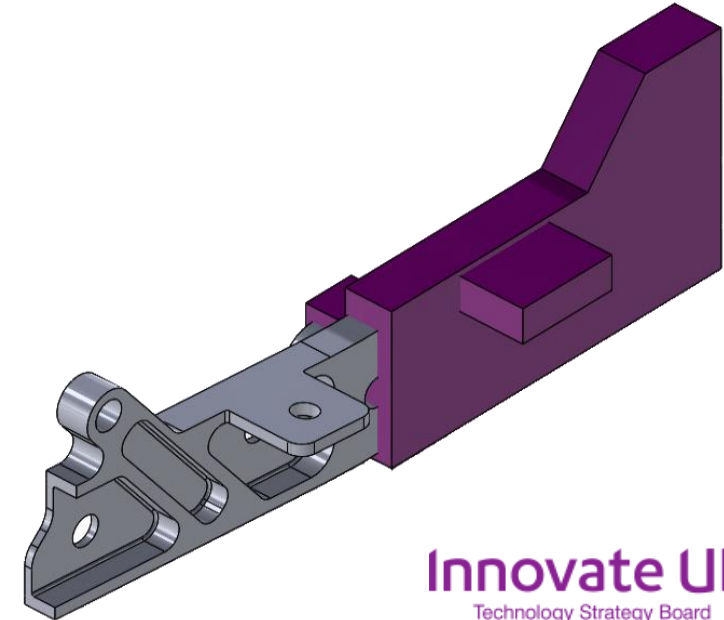
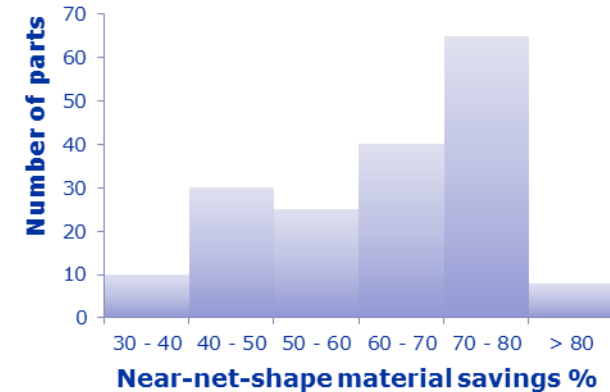


- LFW process Pioneer TWI

- “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)



Innovate UK
Technology Strategy Board

Disclosing joint performance: welding conditions

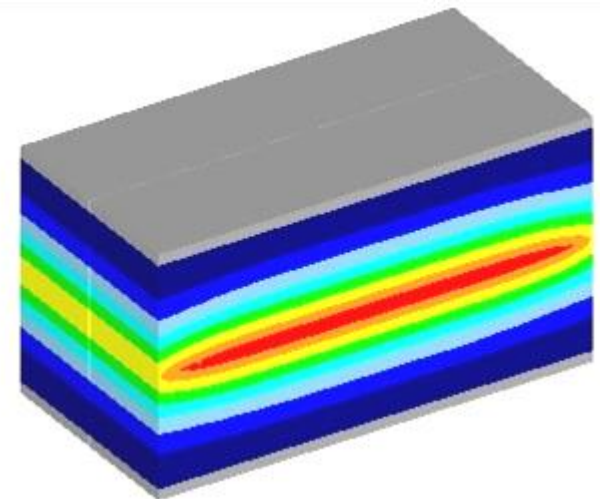
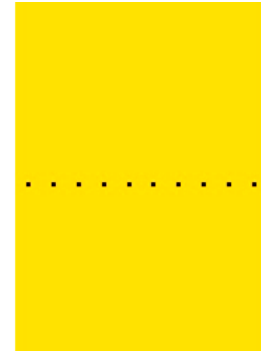
- Process window and welding conditions identified for Ti-6Al-4V Grade 5 AMS4911, 25mm/1in thick plate
- General terms
 - Friction and forge above 40MPa
 - Amplitude and frequency combination above 300 mm/s
 - Burn off, stick out, etc. considered in relation with geometry
- Weld made in atmospheric conditions: **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: $\approx 50\%$ 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

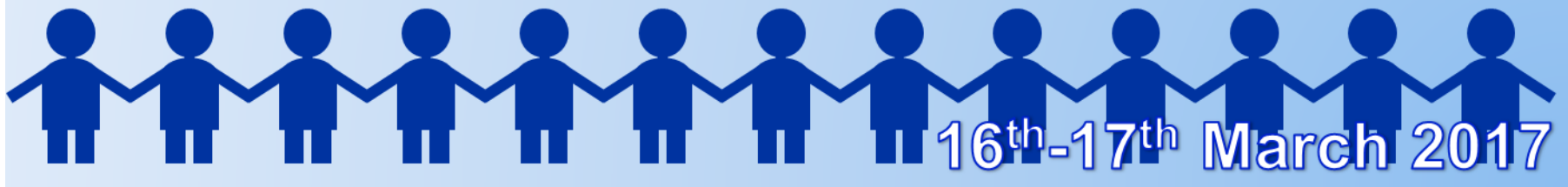
- Anthony McAndrew
Contaminant removal in Ti6Al4V
 - 1st publication: 2013
 - 2nd publication: 2014
 - Thesis: 2015
- Lucie Lee
Novel industrial application
 - 1st publication: 2016
 - 2nd publication: 2017
 - Thesis: 2018

DEFORM



TWI Biennial International LFW Symposium

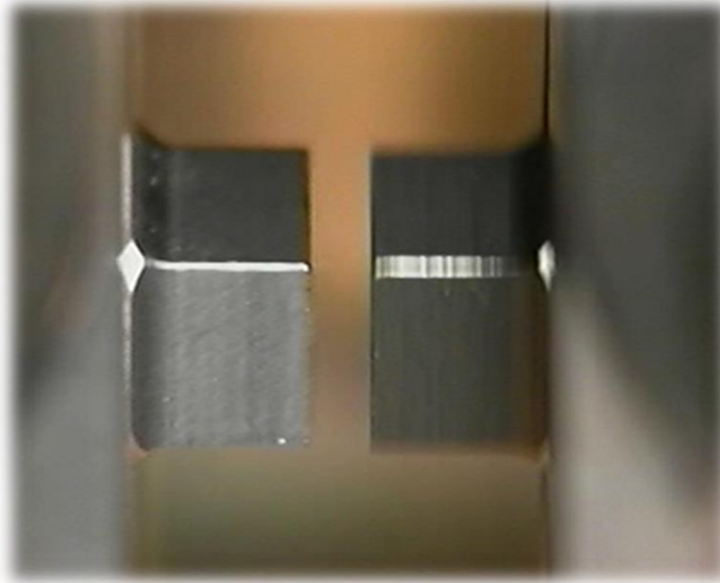
- Leading LFW event worldwide
- Focus on LFW developments
- Presentations by field experts
- Meet
 - Research teams
 - Academia
 - Suppliers
 - End Users



Contact: Richard Freeman, Industry Sector Manager, Aerospace.

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Martin Wood

TiFab Consortium lead

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