Novel technologies to boost the shipyard industry

RESURGAM: WP1
Marinisation of FSW for steel

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ORGANIZED BY THE EU HORIZON 2020 PROJECTS:

FIBRE4YARDS SHIPYARD FOR THE FUTURE

RESURGAM Robotic Survey, Repair and Agile Manufacture

MARI4YARD MARI4ALLIANCE

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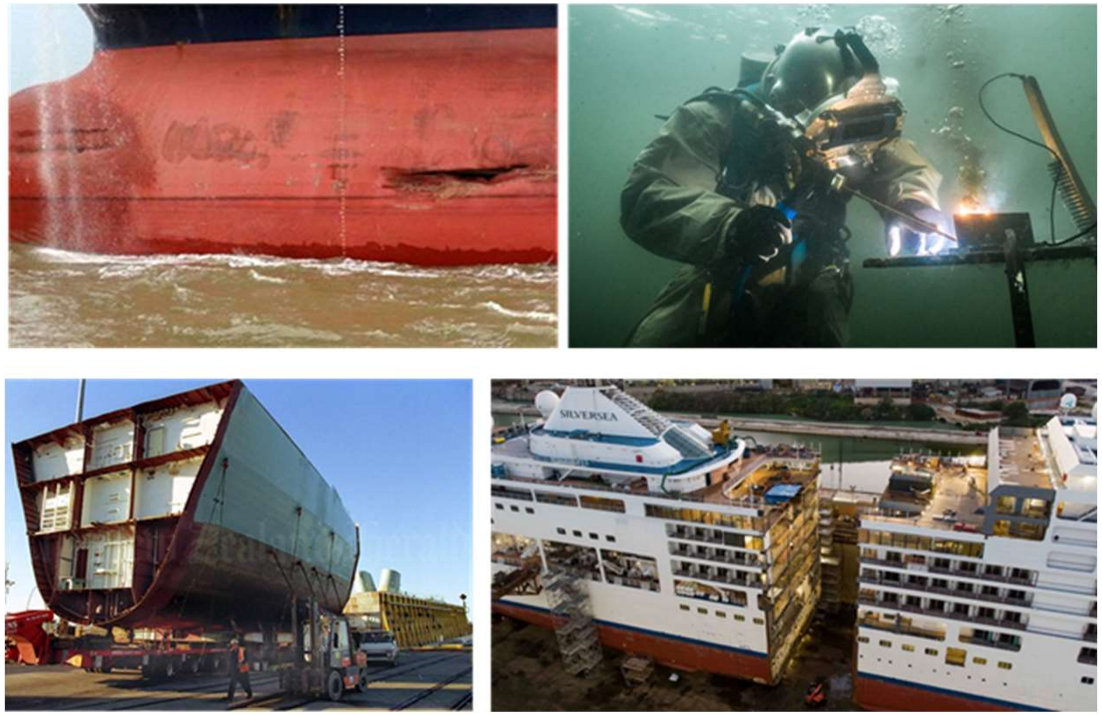
RESURGAM – technical overview



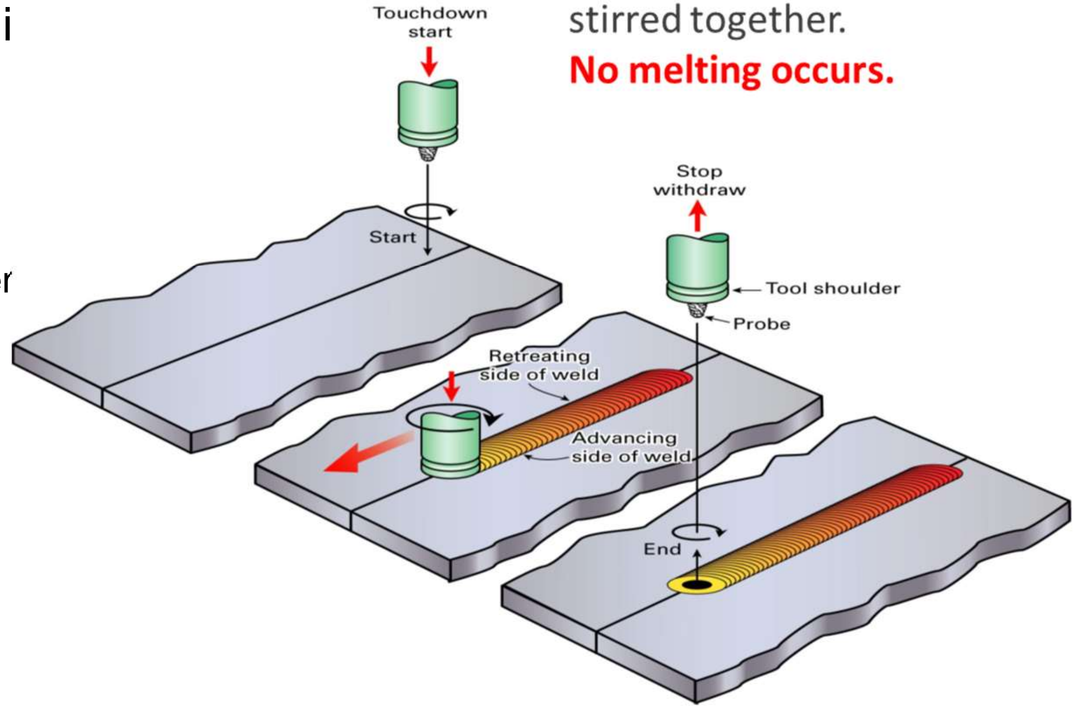
1. Develop FSW tools suitable for welding marine grade steels in air and liquids
2. Establish the performance (longevity and reliability) of FSW tools for steel used in air and water
3. Establish the FSW process envelope for specific tool sizes in air and water
4. Determine the weld properties of marine grade steels welded by FSW in air and water
5. Develop a route map that will enable guidelines to be drawn up to allow the use of steel FSW for marine applications

What is FSW?

- Invented by TWI in 1991 for welding alumini magnesium, copper & titanium.

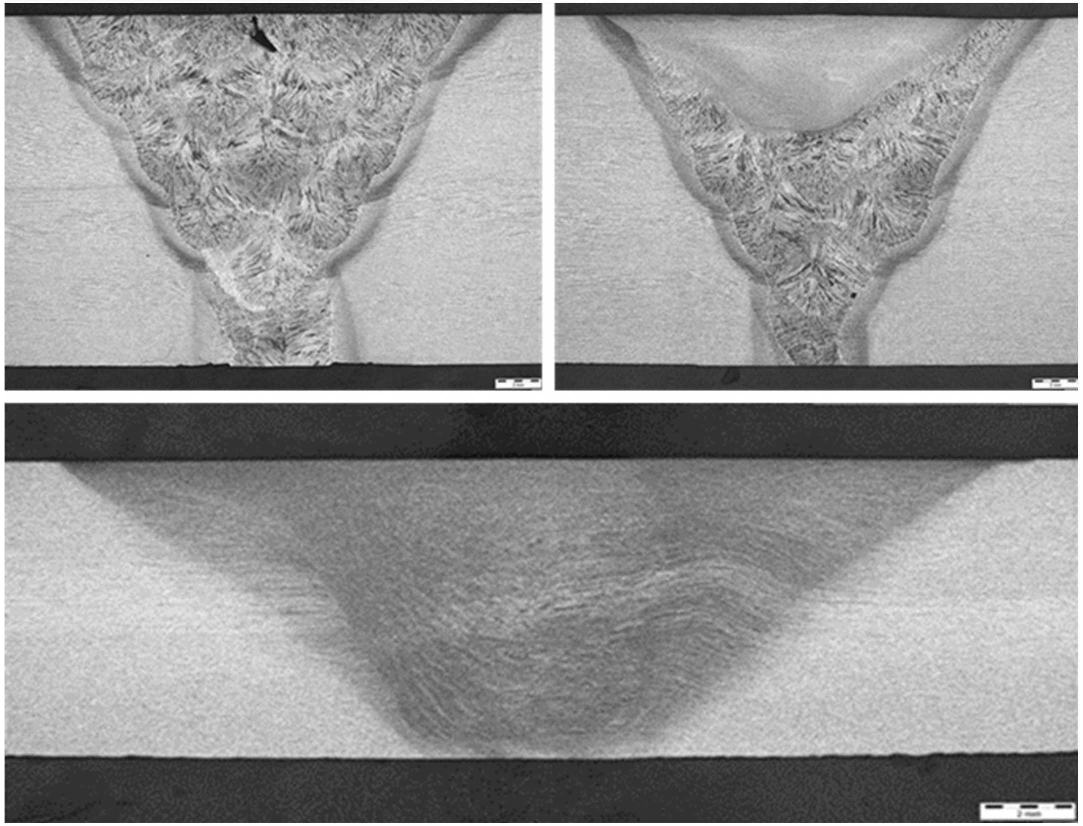
- It is a solid state joining process with
  - Fine grained, wrought microstructure, thus exceller
  - Ideal for single pass, square butt welds;
  - No changes to metal composition;
  - No filler wire required;
  - No molten metal;
  - No sparks;
  - No Fume;
  - No UV or EM radiation;
  - Low energy usage.

Basic principle of FSW:
A rotating tool is used to heat and soften metal, and this is then stirred together.
No melting occurs.

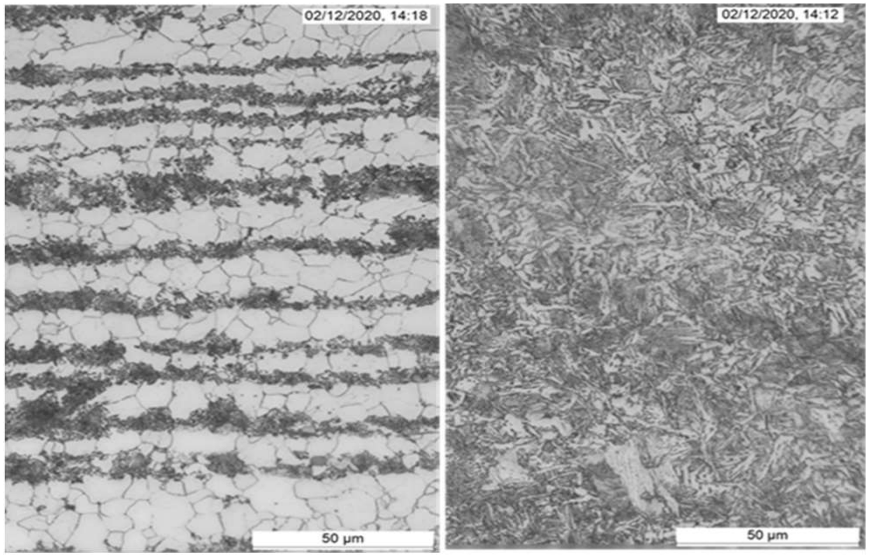


Proven in aluminium for 30 years

Why might FSW in steel be desirable ?

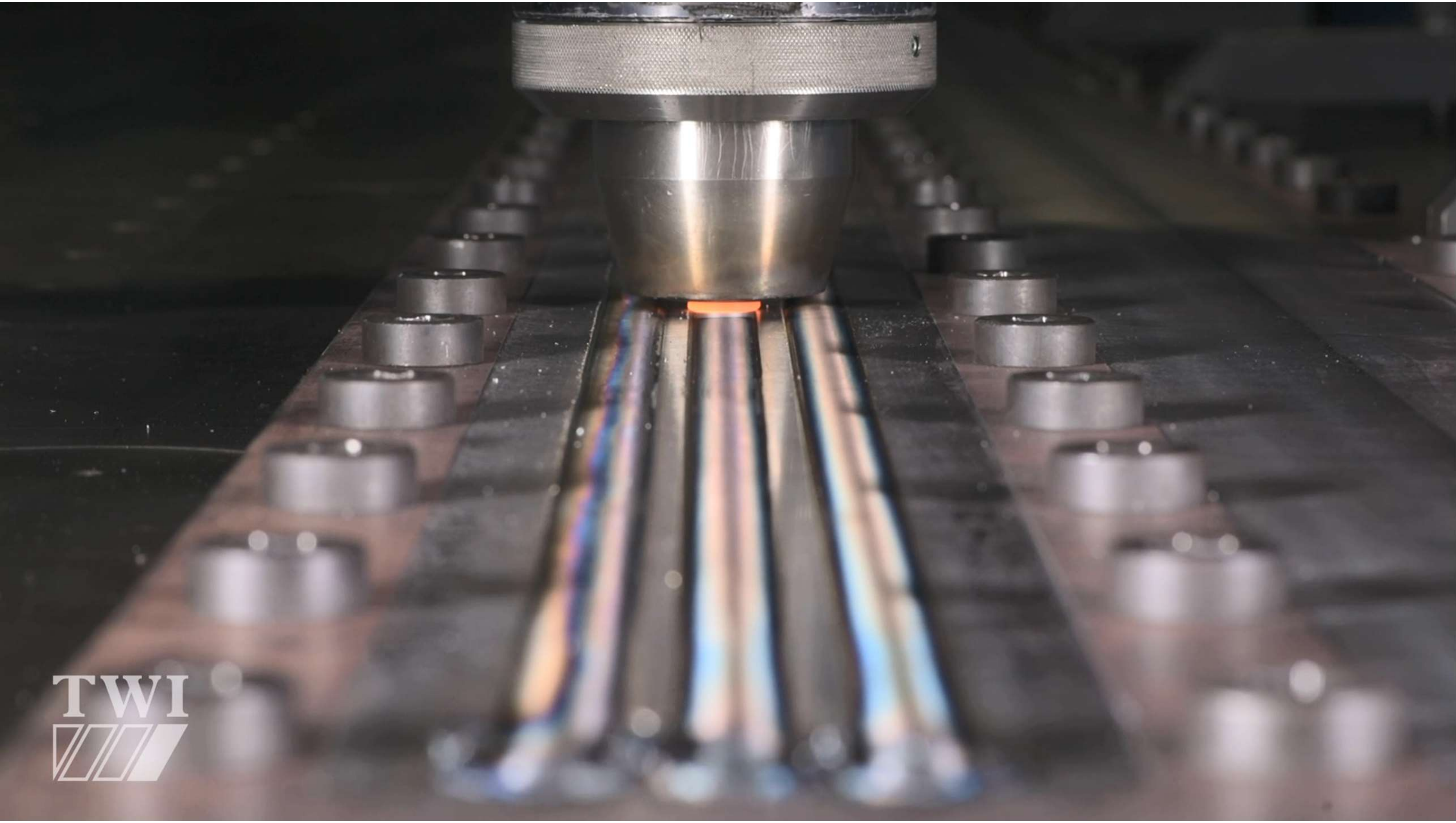


- Friction stir welding produces fine grained, forged microstructures with none of the defects – porosity, inclusions, elemental loss or segregation and hot cracking - usually associated with melting.



History of steel FSW

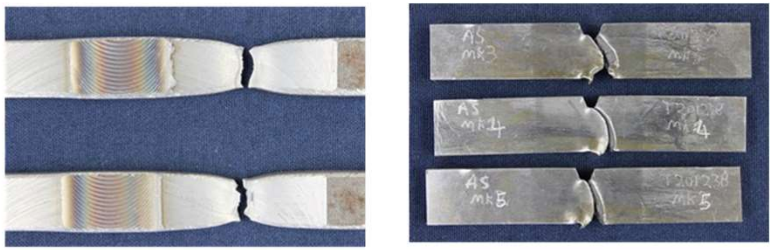
- FSW of steel was first demonstrated only a few years afte process itself was invented.
- As with aluminium, it produces strong, tough, fatigue resis welds with low distortion and can be fully automated for volume production.
- However, as FSW of steel takes place at over 1,000^{o}C an hot steel is extremely reactive, it requires very specialised tools which are more expensive than those used for aluminium and had only a short lifetime.
- TWI has worked with several member companies over many years to develop successive generations of tools for steel FSW.
- A new FSW tool for steel is being introduced to the market by Element Six and TWI has undertaken testing and development work on this tool.
- **Results are very encouraging**.

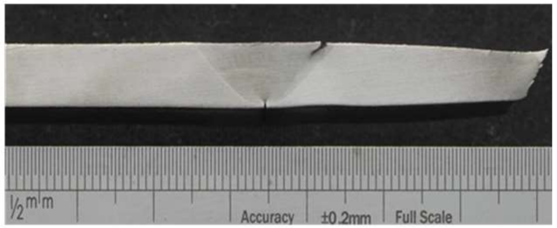


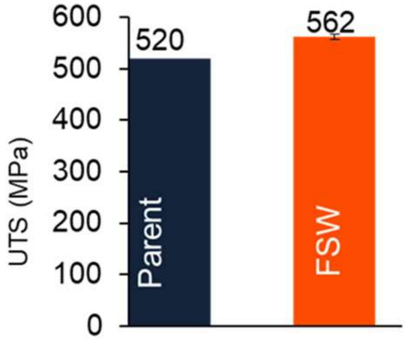
Market drivers for steel FSW

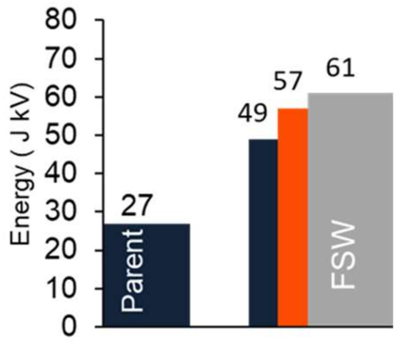
- Why transfer the technology to steel?
  - Enhanced mechanical properties
  - Automation
  - Potentially improved fatigue life
  - Possibility of joining very hard to weld steel grades
  - Able to weld under water and in radioactive environments
  - Reduced susceptibility to hydrogen effects

Property overview



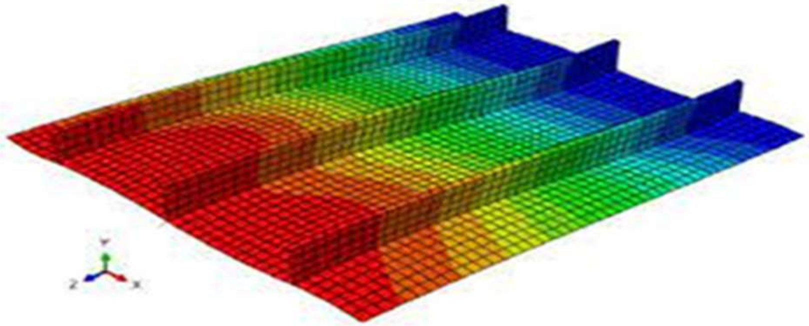


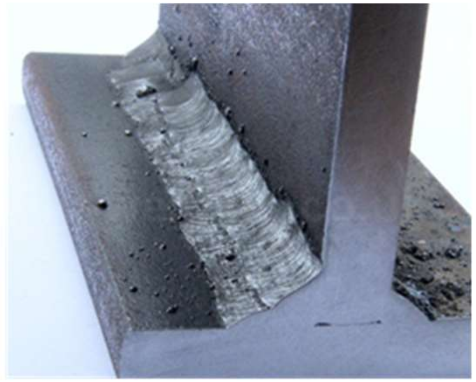


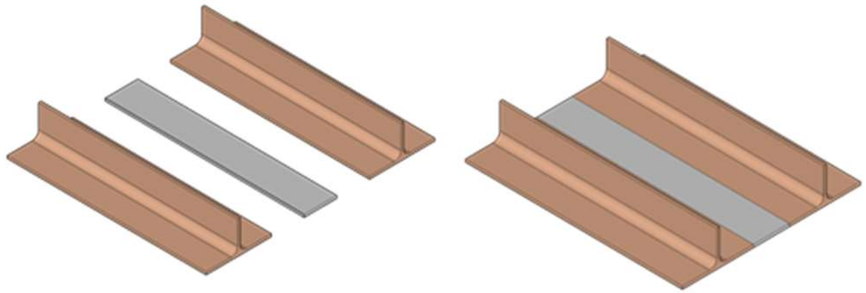


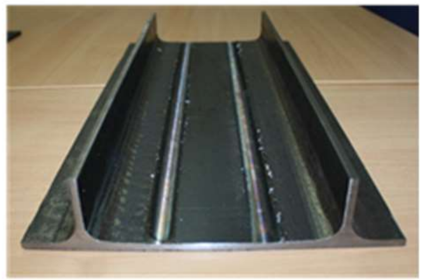
Application 1: Fabrication of stiffened panels

- Replaces two arc fillet welds with one FSW butt weld
- Gives a fully forged structure
- Uses commodity items
- Easier inspection
- Reduced distortion









Application 2: Under water repair

Cost assessment

All the benefits of the process already proven in aluminium apply to steel, producing strong, tough welds in a wide range of steels – including dissimilar grades and those traditionally considered difficult to weld by other processes. However, whereas in aluminium friction stir welding is usually lower cost than other processes, in steel the process *appears* to be more expensive than existing techniques due to the higher cost of tools for steel FSW.

But is it really?

- How much is spent on pre-weld preparation and post-weld clean up with existing processes?
- How much is spent on purchasing, storing and controlling filler wires in existing processes?
- How much is spent on distortion control and rectification during arc welding?
- How much is spent on NDT, QC and rectification during other welding processes?
- How much is spent on purchasing, storing, controlling and disposal of flux in arcs processes?
- How much is spent on welder training and qualification with other welding processes?
- How costly does it become to weld under water with other processes? Is it even possible?
- Would you weld inside an oil pipe or fuel tank with other processes?

If one considers the true costs of welding fabrication, then an automated, mechanical process that produces high quality, tough, strong, fatigue resistant, autogenous welds 24 hours per day may be cost competitive in many applications.

Engineering superhard materials

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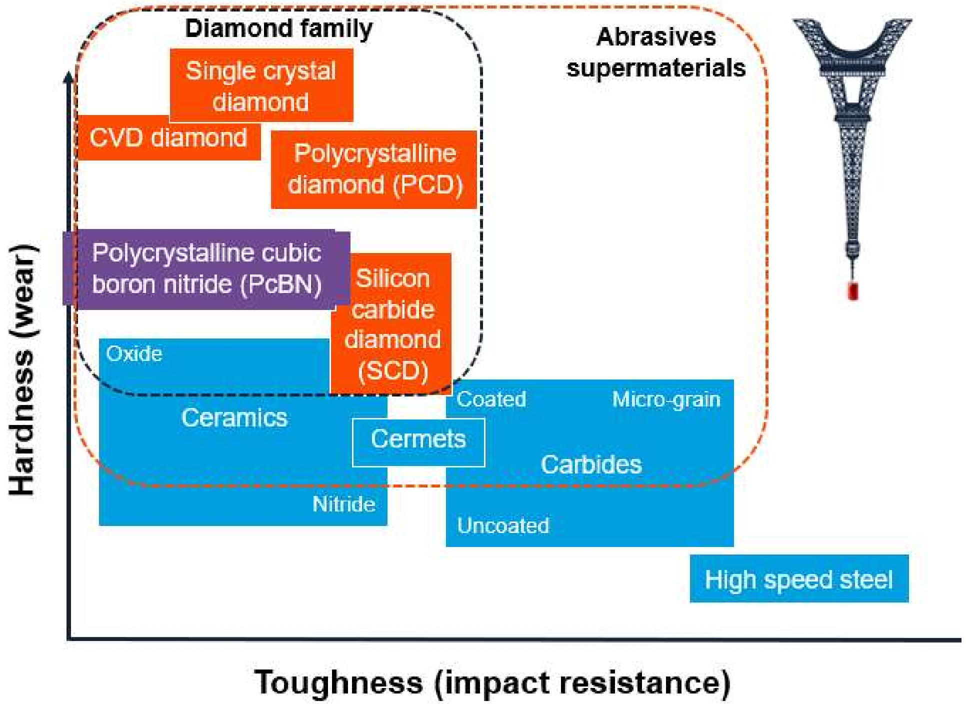
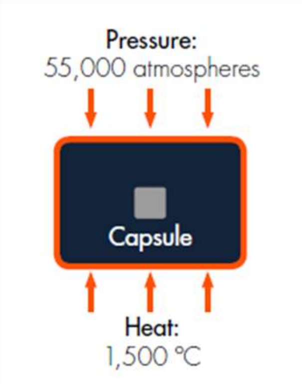
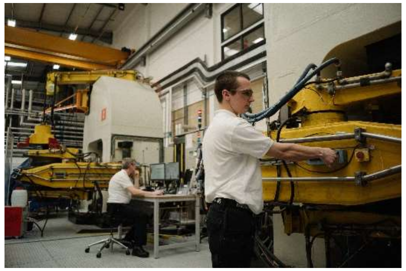
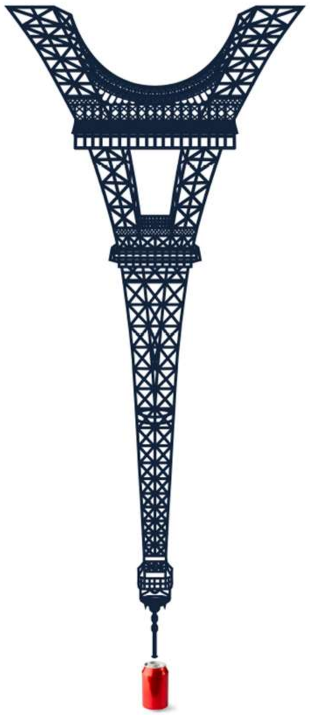


- Element Six has proudly produced diamond-enabled product for >60 years
- We are uniquely equipped to produce the largest bulk PCBN discs in the world
- Reputed for pioneering new technology in the PCBN materials manufacturing
- HPHT capacity for consistent mass production of >50 PCBN-related products

How do we make PCBN







- Synthesis of PCBN starts with powder preparation, carefully choosing different mixing techniques
- Sintering of the powder is done in a controlled capsule under a pressure 4-6 GPa and temperature >1200 ^{o}C
- At such high temperatures and pressure reaction within binder phase with CBN results in a strong composite material
- Controlling pressure, temperature and time is key to achieve good strength in the material

Dynamic modelling for tool design

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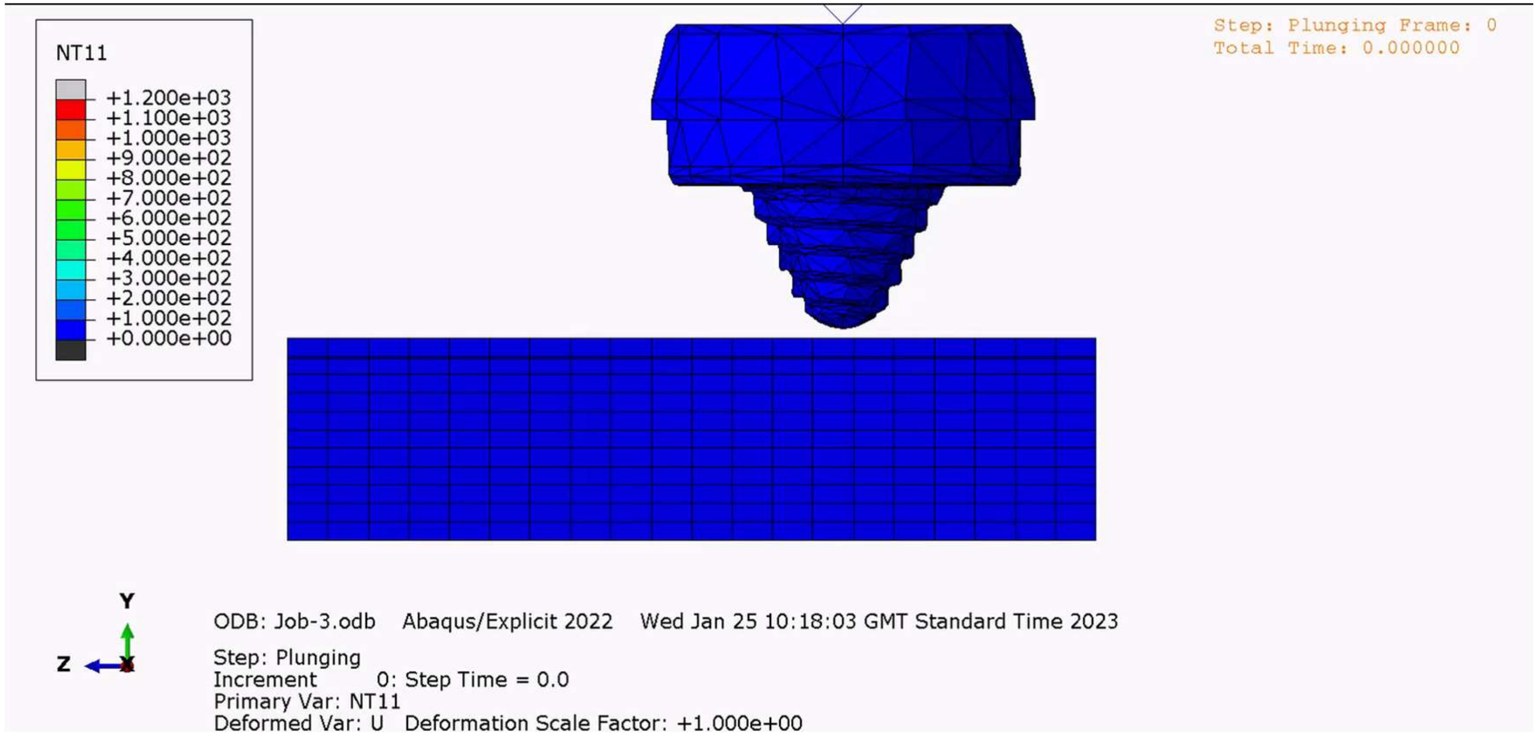

Tool development roadmap

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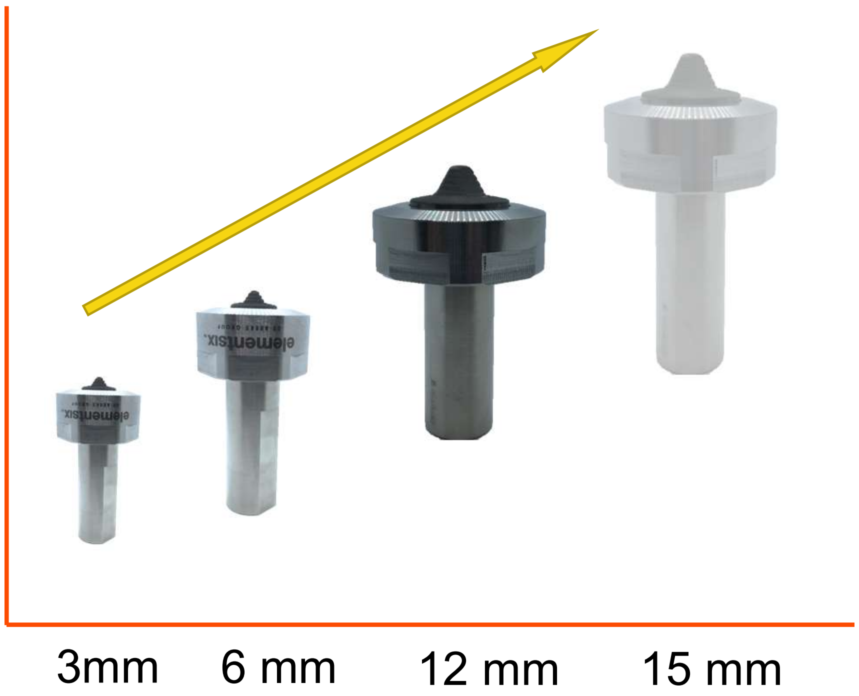

Tool development roadmap

- Developed a flexible platform technology
- End to end control of tool development allows E6 to produce range of tool sizes
- At present E6 is carrying out tool development with 3mm and 12mm tools
- Next step is to explore both different sizes based on requirement also new designs

What have we achieved so far

- Extensive testing proved that the **6mm** tools are consistent in performance
- Maximum life **65m and 29 plunges** against target of 30m and 10 plunges- tools have still life left with 6mm tool
- 12mm tool lasted **35m** against target of 20m
- Excellent mechanical properties of the weld even after **60m of welding**
- Welded stainless steel, high strength steel, different steel grades and **underwater**
- A capability to produce PCBN tools for wide range of sizes from **3mm to 15mm** thick steel plate- A necessary step to change process

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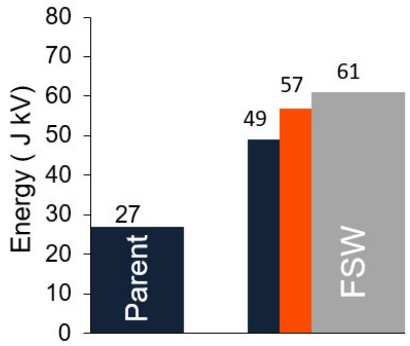
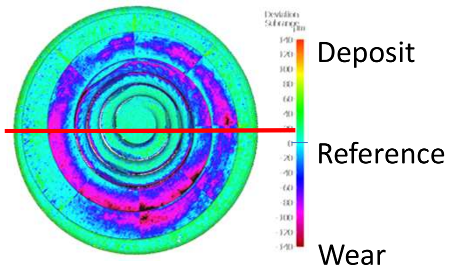
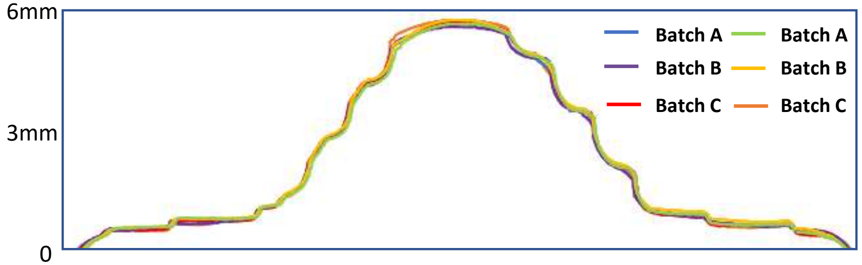


Charpy impact test

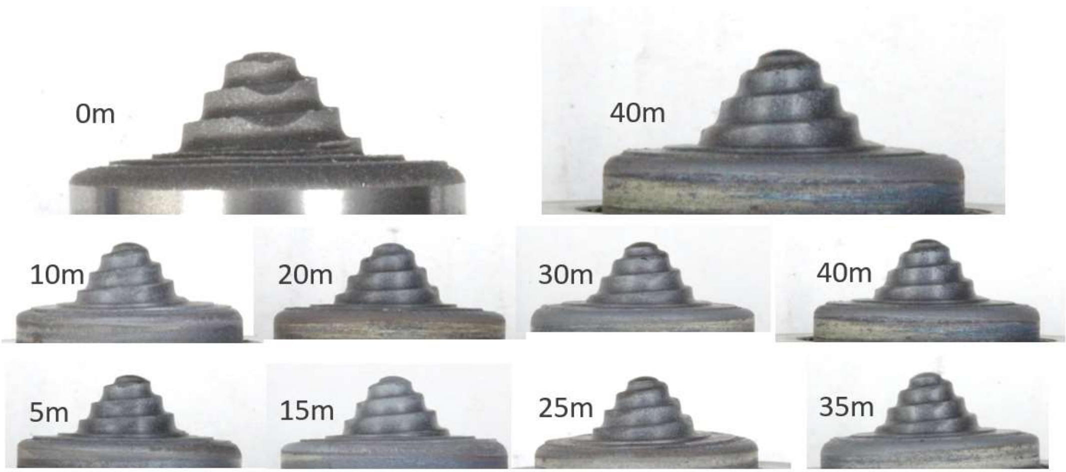
Tool consistency



Cross section profile after 40m



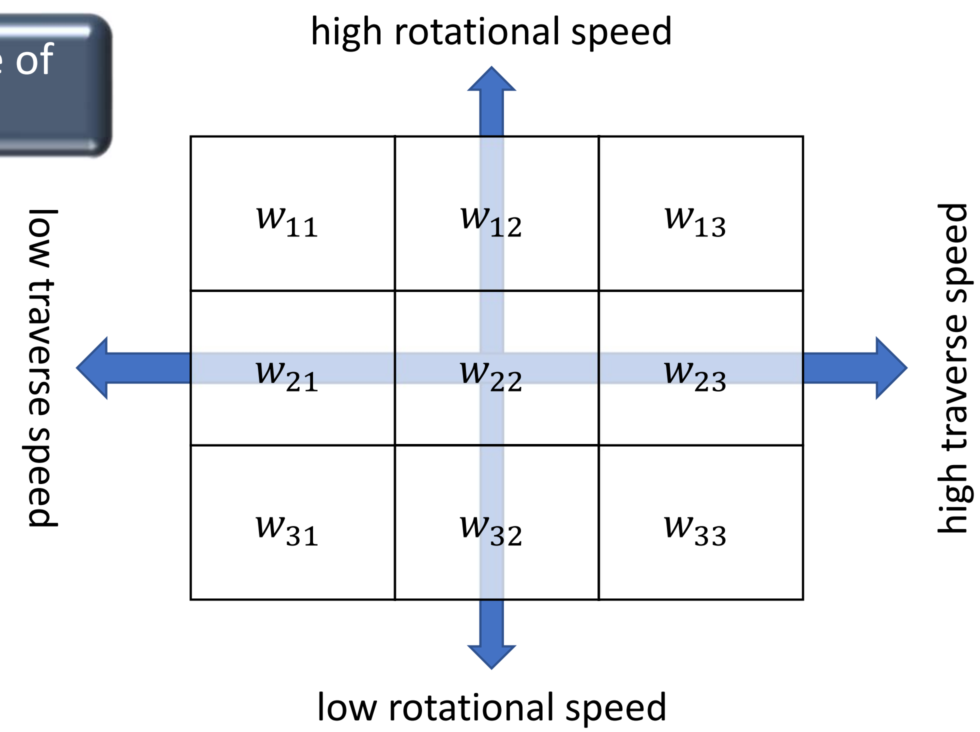
Tools retained features even after 40m of Welding



Testing programme

characterise and optimize the mechanical performance of FSW joints in steel maritime structures

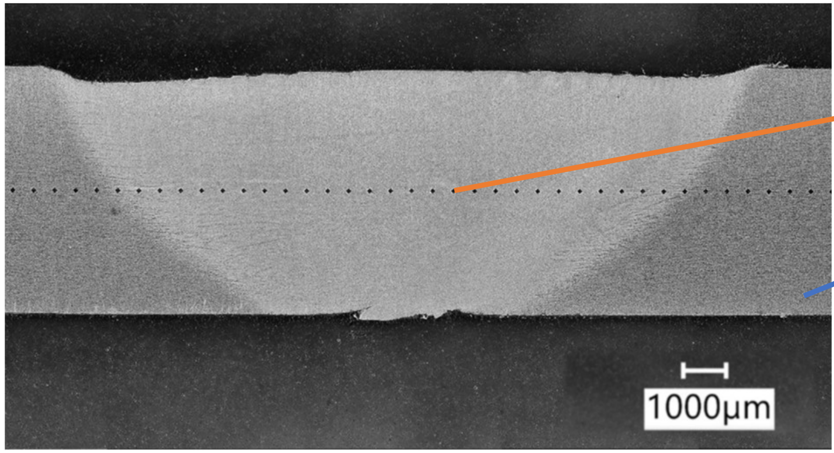
- 2 materials with distinct strength differences
- 2 thicknesses
- $\pm$ 9 combinations of traverse speeds and rotational speeds of the tool per material and thickness combination

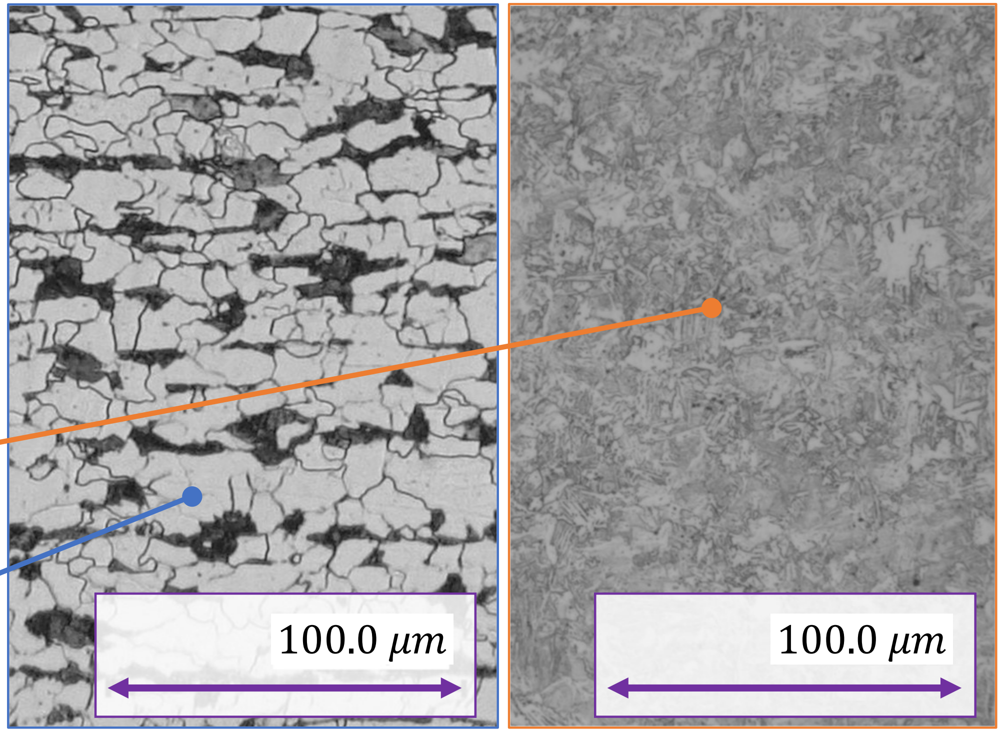


Weld properties – microstructure

Steel phases and grain size

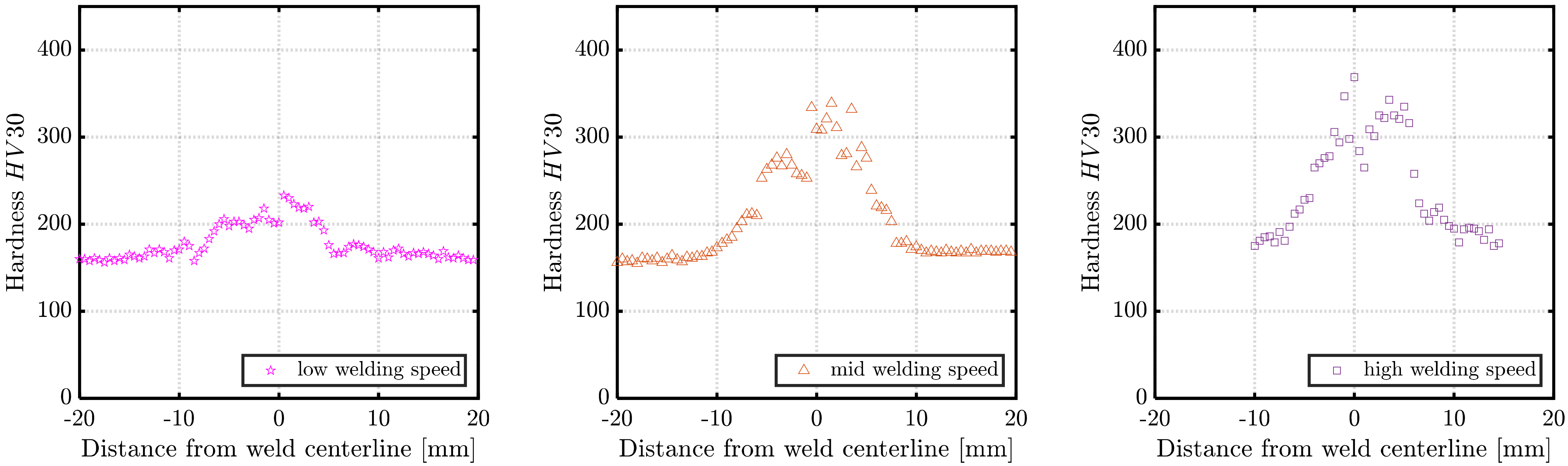
- FSW produces a fine-grained wrought microstructure consisting of steel different steel phases such as ferrite, pearlite, acicular ferrite, possibly bainite and martensite





Weld properties – microstructure

Hardness

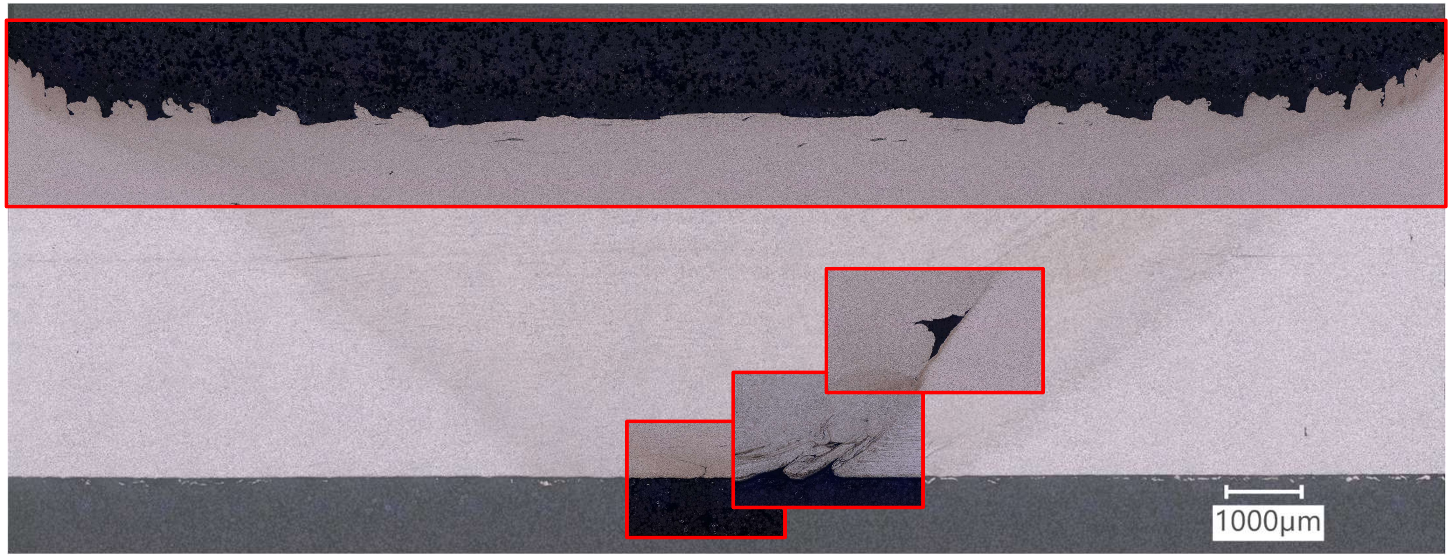


Weld properties – microstructure

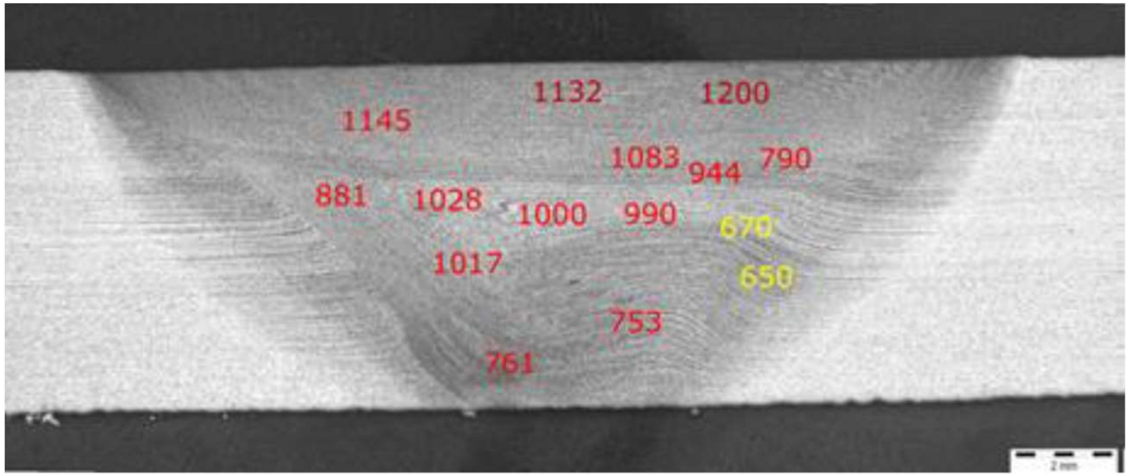
Imperfections

- such as voids, surface roughness, lack of mixing and lack of penetration can occur as a result of poorly chosen welding parameters or other processing parameters

- Properly chosen welding parameters results in defect free welds



Weld properties – distortion



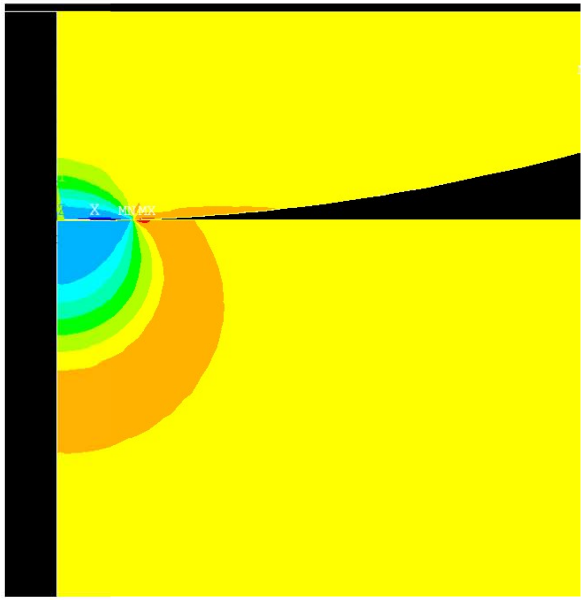
Weld properties – strength

- 1m long weld in 12mm thick steel
  - The tensile strength varied less than 2% along the entire weld length.
  - All samples failed in the parent metal at around 600 MPa
  - The weld metal itself was determined to have an UTS of around 760 Mpa
- Similar weld with intentionally created 2mm void
  - Majority failed in welded material around 550 – 600MPa, some in parent material around 600MPa
  - Weakest test piece failed at 506 MPa – which is approximately 84% of the parent metal strength despite the presence of a large internal defect

Weld properties – strength

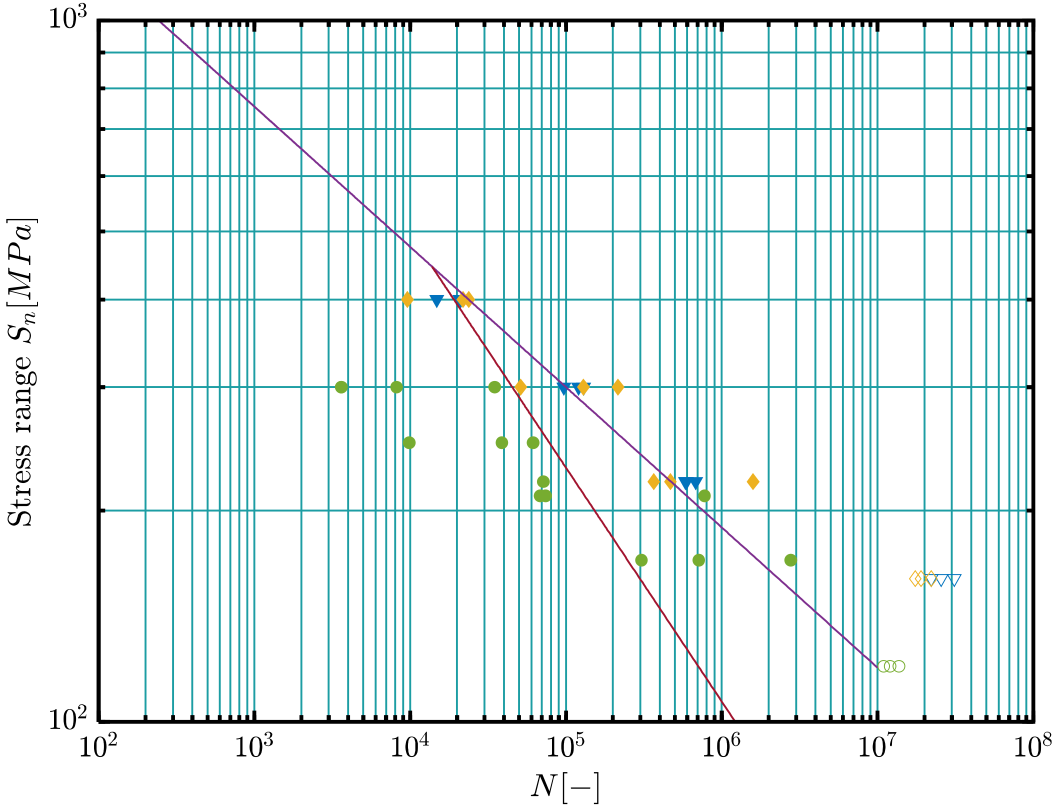
- Joint strength determined by:
  - surface conditions
  - base material
  - microstructural defects
  - <u>welded material strength</u>

Plastometrex



- Welded material strength found with estimated YS over 800MPa and UTS over 1000MPa

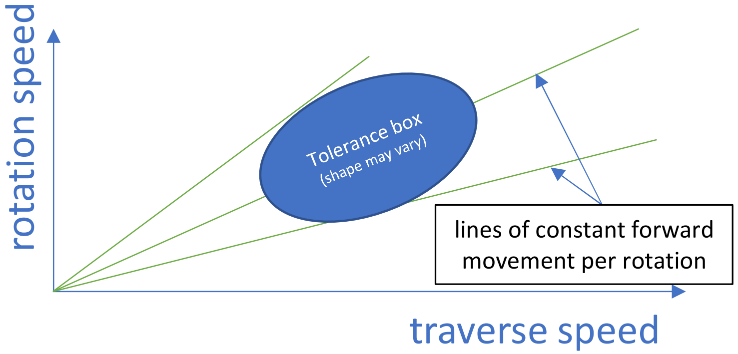
Weld properties – fatigue

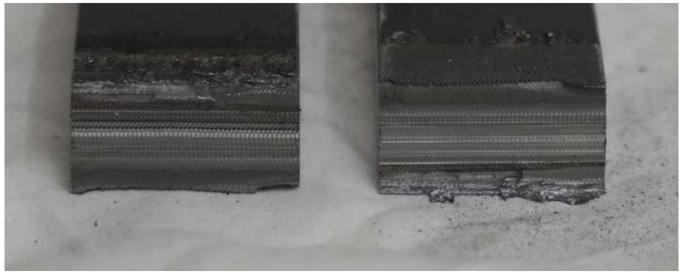


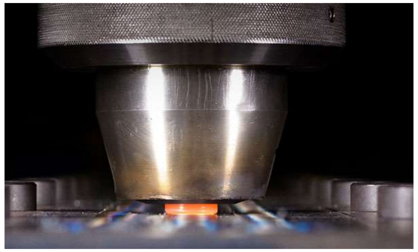
- In the absence of defects, cracks initiate at the weld toe growing through the HAZ
- Fatigue resistance largely dominated by microstructural imperfections
- Defect free welds often show slope similar to and fatigue strength higher than base material

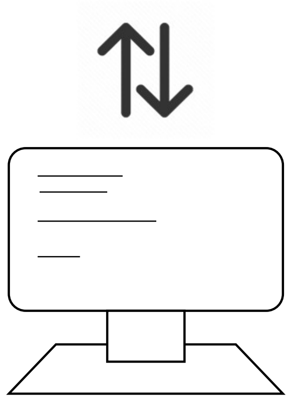
low welding speed: $\log(C) = 19.5$, $m = 5.84$, $\sigma = 0.06$
mid welding speed: $\log(C) = 20.1$, $m = 6.08$, $\sigma = 0.26$
high welding speed: $\log(C) = 24.5$, $m = 8.33$, $\sigma = 0.41$
FAT160
FAT80

Industrialisation considerations









Summary

- We can make good welds using a reliable, repeatable, automated process;
- Have an understanding of the relationship between microstructure and properties;
- Have a clear idea of future tool and process development;
- Know how to apply the technology industrially for the two project applications
  - Modular build using retrofit systems
  - At sea repair
- Both of which will be explored in further detail in the later session

Potential other applications for FSW in steel

- Pipelines
- Wind turbines
- Pressure vessels
  - Can produce welds with significant toughness and fatigue resistance
- Armour
  - Can produce hard, tough surface layers
  - Can weld very high alloy content steels
- Hydrogen infrastructure
  - No arcs to dissociate moisture to H and O
  - No molten weld pool to absorb hydrogen
  - Fine grained microstructure seems to resist hydrogen permeation
- Automotive

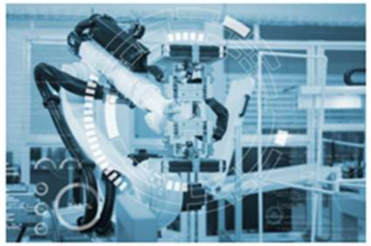

Shipbuilding


Oil and Gas infrastructure


Space and aerospace


Renewable Energy


General engineering


Automotive

THANKS FOR YOUR ATTENTION

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