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Skills needs

What a person needs to know and be able to do

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Outline

- **Technical skills for three advanced welding processes**
  - Introduction, skill framework and roles
  - Common skill baseline for all three processes
  - Electron beam welding (EBW) – skill profile
  - Friction stir welding (FSW) – skill profile
  - Hybrid laser arc welding – skill profile
  - Skills comparison of the three processes
  - Development and qualification pathway

Technical Skills – Introduction

- **Why these three processes are looked at in terms of skills**
  - EBW, FSW and hybrid laser welding are mechanised or automated processes: weld quality is decided before the beam, arc or tool starts moving
  - The classical manual skill of the welder plays a minor role; the ability to prepare, set, verify and monitor a machine dominates
  - Each of the three needs a different core discipline – vacuum and beam physics (EBW), machine tools and forces (FSW), optics combined with arc welding (hybrid)
  - Competence therefore has to be demonstrated and recorded, not assumed: ISO 14732 and ISO 25239-3 formalise this for operators and weld setters
  - For each process this presentation maps knowledge, equipment, parameter, inspection and safety skills

Technical Skills – Framework

- **Five skill domains used throughout this presentation**
  - Knowledge base – process physics, metallurgy and material behaviour
  - Equipment skills – setting up, operating and maintaining the machine and its tooling
  - Parameter development – building, optimising and qualifying the welding procedure
  - Inspection and quality – recognising imperfections, selecting NDT, applying acceptance criteria
  - Safety and compliance – hazards, PPE, standards and documentation

  - The same five domains are used for each process, so the three skill profiles can be compared directly at the end

Technical Skills – Roles

- **Who needs which skills?**
  - Machine operator / weld setter (ISO 14732)
    - Loads and clamps parts, starts and monitors the weld, reacts to deviations; the setter is additionally qualified to set the parameters
  - Welding coordinator / responsible welding engineer (ISO 14731)
    - Selects the process, writes and qualifies the WPS, approves tools and consumables, supervises production and personnel
  - Inspector and NDT personnel (ISO 9712)
    - Checks fit-up and cleanliness, performs visual and volumetric testing, judges results against acceptance criteria
  - Maintenance and service technician
    - Electron gun, optics, spindle, vacuum system, sensors; calibration and validation of equipment (ISO 17662)

Technical Skills – Common baseline (1/2)

- **Engineering knowledge shared by all three processes**
  - Materials and weldability: aluminium, magnesium, copper, carbon and stainless steels, nickel and titanium alloys
  - Typical metallurgical risks: hot cracking, porosity, loss of strength in precipitation-hardened alloys, evaporation of volatile alloying elements
  - Heat flow and cooling rate, and their effect on microstructure, hardness and toughness
  - Distortion and residual stress – why low heat input reduces both, and how clamping redistributes them
  - Joint design and the fit-up tolerance that a mechanised process can accept
  - Reading technical drawings and welding symbols (ISO 2553)
  - Practical metrology: vernier caliper, thickness and feeler gauges, dial indicators, straightness and flatness checks

Technical Skills – Common baseline (2/2)

- **Quality, documentation and safety skills shared by all three processes**
  - Working strictly to a WPS and recording what was actually done – traceability of parts, tools and parameters
  - Understanding qualification logic: procedure qualification (ISO 15614 series, ISO 25239-4) and personnel qualification (ISO 14732, ISO 25239-3)
  - Destructive testing basics: macro-section, tensile, bend, hardness and, where required, impact testing
  - Selecting NDT and knowing its limits – visual, penetrant, radiographic, ultrasonic and phased-array testing
  - Reading an acceptance standard and applying the correct quality level
  - Data literacy: interpreting process-monitoring charts, signal traces and log files instead of judging by appearance alone
  - Machine safety culture: risk assessment, guarding and interlocks, isolation before intervention, PPE, emergency-stop discipline

EBW – Skill profile

– **Character of the process**
  - A high-vacuum, high-voltage, CNC-controlled fusion process – operating it resembles running a precision beam instrument more than welding by hand
  - Extremely small tolerances: the focused spot can be below 0.05 mm and joint gaps are typically kept under 0.1 mm
  - No filler metal and no shielding gas, so nothing compensates for a poor fit-up
  - Small changes in any parameter noticeably change the weld, so strict process control is mandatory

– **Dominant skill areas**
  - Precision joint preparation · vacuum and beam technology · beam diagnostics · CNC programming · radiation and high-voltage safety

EBW – Knowledge base

- **What the person has to understand**
  - Electron generation and acceleration: cathode or filament, anode, bias voltage – and what the kV and the mA each control
  - Beam optics: magnetic focusing lens, deflection coils, working distance, spot size, power density, astigmatism
  - Vacuum physics: why electrons are scattered by gas molecules, the usual pressure ranges, and the difference between high, medium and non-vacuum modes
  - Keyhole mode versus conduction mode and the resulting depth-to-width ratio, which can reach 25:1
  - Behaviour of materials under vacuum: magnesium and zinc evaporation, hydrogen porosity in castings, breakdown of the alumina layer, heat pumping in copper
  - X-rays as an unavoidable by-product of electron impact

FSW – Skill profile

- **Character of the process**
  - A solid-state, force-driven process: the skill set is much closer to CNC machining than to fusion welding
  - No arc, no filler wire, no shielding gas – heat comes from friction and the material is worked at roughly 80–90 % of its melting temperature
  - Quality is governed by down force, rotation speed, travel speed, tilt angle, plunge depth and above all by tool geometry
  - The workpiece must be clamped rigidly and the anvil must not deflect, so fixturing is an engineering task in itself

- **Dominant skill areas**
  - Machine-tool and robot competence · tool selection and wear judgement · fixture and clamping design · force and torque monitoring

FSW – Knowledge base

- **What the person has to understand**
  - Frictional heat generation and the forging action of the shoulder, and the stirring action of the pin
  - Material flow around the tool, the advancing and retreating sides, and the weld zones: nugget, thermo-mechanically affected zone and heat-affected zone
  - Why 2xxx and 7xxx aluminium alloys, magnesium and copper are far easier to join in the solid state than by fusion
  - Tool material requirements for steel and titanium – PCBN and tungsten-based tools – and their temperature and wear limits
  - The interaction between rotation speed, travel speed and peak process temperature
  - Process limitations: sensitivity to joint tolerances, need for a backing bar or anvil, the exit hole, and the inability to fill gaps or deposit material

Hybrid LW – Skill profile

– **Character of the process**
  - Two heat sources acting in one common process zone: a laser keyhole and a GMAW arc, with filler wire added
  - The person therefore needs real competence in both laser welding and arc welding – the widest knowledge base of the three processes
  - The filler metal bridges gaps and controls the metallurgy, which makes fit-up less critical than in EBW but adds consumable and gas management
  - Process configuration is a deliberate choice: a leading laser suits butt welds, a leading torch suits fillet welds

– **Dominant skill areas**
  - Dual-process parameter development · beam and arc coupling · optics handling and cleanliness · seam tracking · laser and fume safety

Hybrid LW – Knowledge base

- **What the person has to understand**
  - Laser side: source types and beam quality, focal length and focal position, spot diameter, power density, keyhole formation, plume and plasma suppression
  - Arc side: GMAW fundamentals, the difference between MIG and MAG shielding gases, metal transfer modes, pulsed and synergic programs, wire and gas selection
  - How the two interact: the keyhole stabilises the arc, penetration increases, and the filler metal bridges gaps and shapes the flanks
  - Effect of the configuration on the weld shape – a cone-shaped weld with the laser leading, a cup-shaped weld with the arc leading
  - Metallurgical control through filler addition: dilution of the base metal, cracking tendency, toughness, and the fine grain structure produced by low heat input
  - The variants and what changes with each: laser with MIG/MAG, with TIG, or with plasma arc welding

Skills comparison

Skill aspect	EBW	FSW	Hybrid laser arc welding
Core discipline	Vacuum and beam technology	Machine tools and force control	Laser optics plus arc welding
Manual welding skill	Very low; no filler, no arc	Very low; a machining-type skill	Low to medium; arc knowledge essential
Most critical preparation skill	Gap below ~0.1 mm, vacuum-level cleanliness, de-magnetising	Rigid clamping and a stiff anvil, correct tool selection	Edge preparation and fit-up, optics cleanliness
Key parameters to master	Beam voltage and current, travel speed, focus, vacuum level	Rotation speed, down force, travel speed, tilt, plunge depth	Laser power and focal position, wire feed, arc-to-beam distance
Monitoring skill	Beam diagnostics, vacuum level, viewing system	Force, torque and temperature signatures	Seam tracking, power and plume monitoring, spatter
Dominant safety skill	X-ray shielding and high voltage	Mechanical, rotating tool and noise	Class 4 laser, arc radiation and fume
Qualification route	ISO 15609-3, ISO 15614-11, ISO 14732	ISO 25239-3 and ISO 25239-4	ISO 15609-6, ISO 15614-14, ISO 14732

Technical Skills – Development pathway

– **How these skills are actually built**

- Start from a recognised welding-engineering base – the IIW and EWF routes (IWE, IWT, IWS, IWP) supply the metallurgy, design and quality foundation
- Add process-specific theory: beam and vacuum technology, solid-state joining and material flow, laser materials processing and arc physics
- Take equipment-specific training from the machine or tool supplier; for EBW and FSW this is practically unavoidable
- Accumulate supervised hands-on time: set-up, parameter trials, and sectioning and examining your own test welds
- Obtain formal qualification: ISO 14732 for beam and hybrid operators and weld setters, ISO 25239-3 for FSW operators
- Ensure welding coordination competence to ISO 14731 for the responsible engineer, and ISO 9712 certification for NDT personnel
- Maintain competence: observe validity periods, re-qualify, and keep records of welds, parameters and tool changes

Technical Skills – Summary

– **Key messages**

- All three processes move the skill from the welder's hand to the setter's head: preparation, parameters and monitoring decide the quality
- EBW demands precision, vacuum and beam physics, with ionising radiation and high voltage to manage
- FSW demands machine-tool thinking: force, rigidity, tooling, and the ability to read a force signature
- Hybrid laser welding demands the broadest skill set, because laser and arc competence are needed at the same time
- Common to all three: materials and weldability knowledge, fit-up discipline, understanding of NDT limits, documentation and standards
- In every case competence has to be demonstrated and recorded – which is exactly what the qualification standards are for

Thank you!

Charalampos Sokos
WGI



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