Smarter Steel: Eliminating Waste in the Race to Net Zero

An Adaptive Digital Twin Framework for Sustainable Steel Forming

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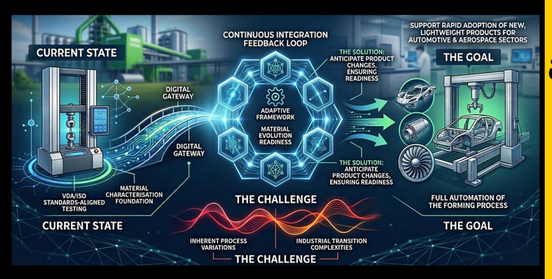
Why this matter for the UK?

As the UK moves toward **Net Zero** and s**ustainable steel**, it needs a scientific basis to understand how l**ow-CO2 steelmaking** affects mechanical properties, performance, and evolving material specifications. This is especially important in automotive manufacturing, where changes may require re-assessment of product **homologation** and precise control of **VDA-compliant** bending. Our **Autonomous Digital Twin** replaces manual trial-and-error with rapid, **data-led decision support**, enabling faster adoption of validated **next-generation** materials and helping safegurds the UK's leadership in **high-value** automated manufacturing and provides the **analytical intelligence** required to convert material development and homologation into a consistent industrial advantage.

Project-specific outcomes

- **Faster setup:** Automated calibration replaces manual trial-and-error.
- **Zero-waste:** Real-time correction eliminates scrap from material variability.
- **Prediction accuracy:** Validated against VDA/ISO industrial standards.
- **Live-Data Integration:** Force, displacement, and imaging update the twin instantly.
- **Industry 4.0 readiness:** A scalable platform for sustainable British manufacturing.

The path to automated sustainability



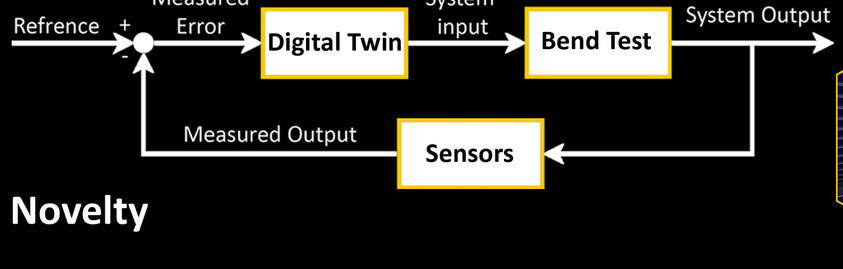
What is a digital twin in this project?

In this framework, the Digital Twin is a **dynamic, virtual mirror** of the **physical process**. It continuously ingests live sensor data to update its internal physics-based state. By synchronising FEM modelling with AI-driven predictions, the twin provides the "intelligence" to anticipate and correct springback before it occurs.

Inputs: Force, displacement, and imaging
Outputs: Bend angle, springback, and quality indicator

Three-layer digital twin architecture implementation in this project

Physical-digital linkage logic
Dynamic & interconnected



Fluid coupling, shown as three layers for clarity

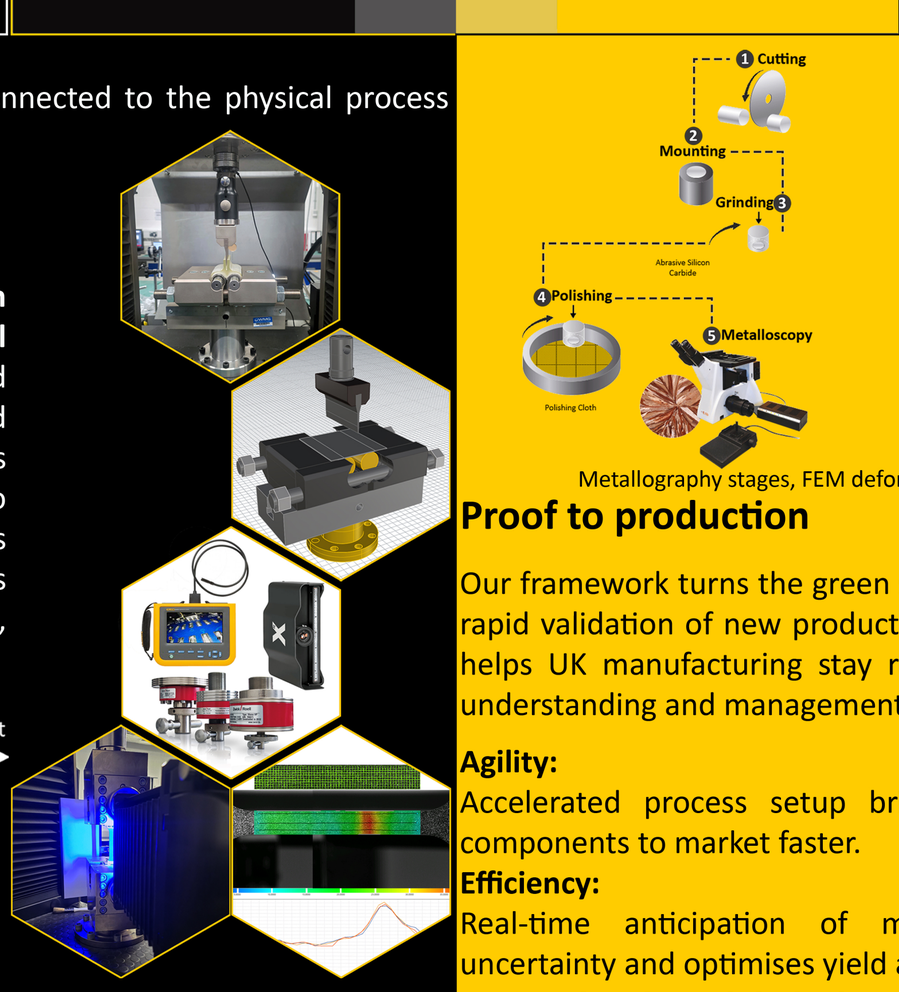
A simulation model becomes a Digital Twin when it is connected to the physical process through real-time data exchange and state updating.

Aim & scope

This research develops and validates a **real-time digital twin** framework for **bending advanced high-strength steel** (AHSS). By integrating **VDA-compliant** testing with a staged physical–digital workflow, we provide evidence-based decision support for complex forming. The system links **in-situ sensing** with a **hybrid AI–physics architecture** to predict and correct material behaviour in real time. This creates a **scalable solution** for **high-value** autonomous manufacturing across all **UK strategic industrial sectors**, such as automotive and aerospace.

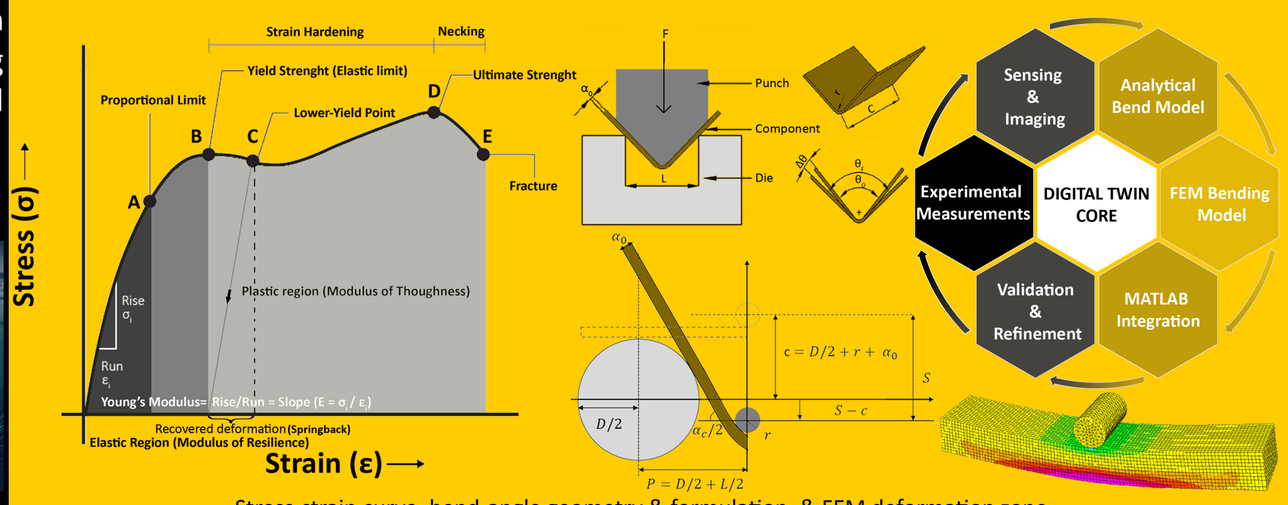
Novelty

Our middleware synchronises physical tests with digital models. This unique feedback loop identifies batch-to-batch variability in real-time, a critical breakthrough for the autonomous production of sustainable steel.



Methodology framework

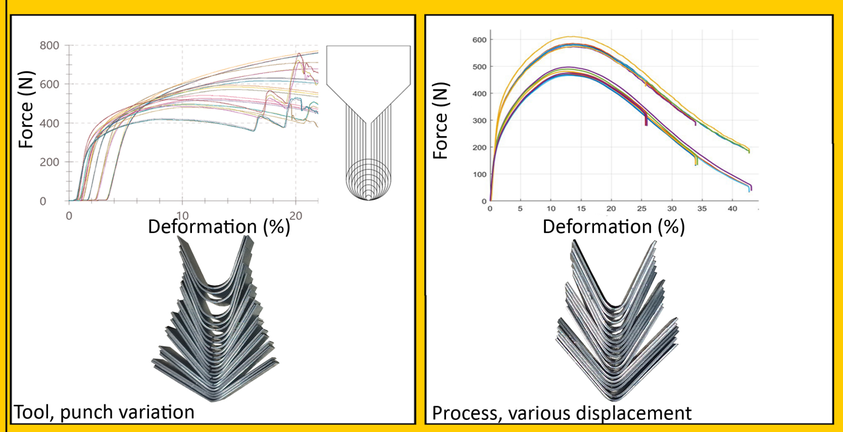
Measurement: Force-displacement and imaging during standards-aligned 3-point bending.
Mechanics: Bending and springback define elastic-plastic deformation and shape recovery.
Formulation: Analytical bend-angle model from tooling geometry and displacement.
Modelling: An FEM-based bending model focuses on the contact region and material deformation zone.



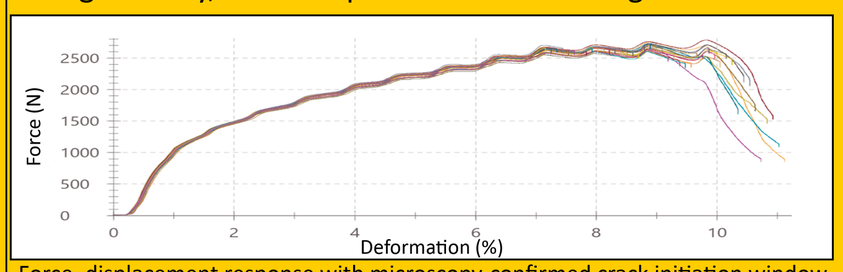
Stress-strain curve, bend-angle geometry & formulation, & FEM deformation zone

Exploration: DOE sweep of geometry, process parameters and material variability.
Characterisation: Tensile testing and microscopy provide material properties to inform and validate the model.
Validation: Model outputs are compared with experiments for iterative refinement.

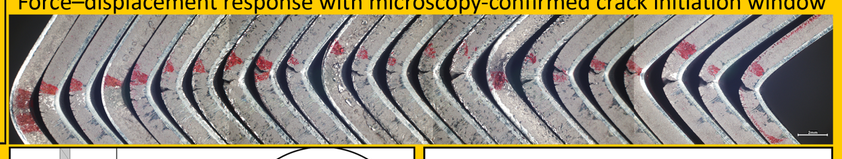
Results

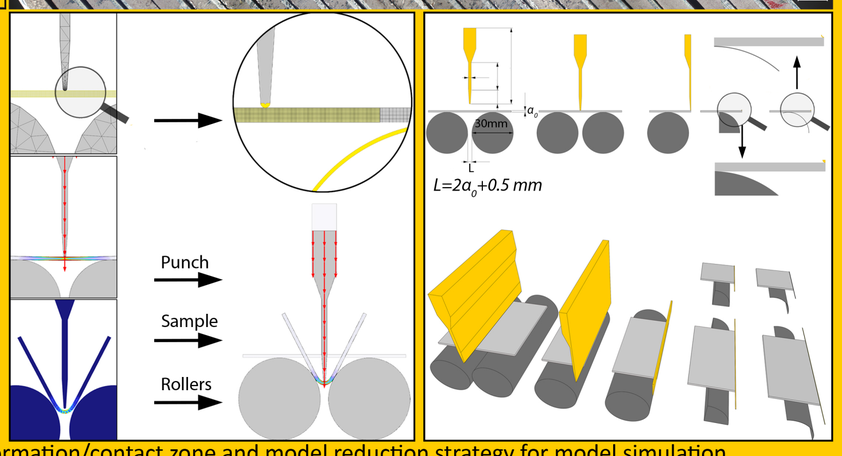


Tool & process variation measurably shift the response and final geometry, the twin predicts the bend angle within the



Force–displacement response with microscopy-confirmed crack initiation window



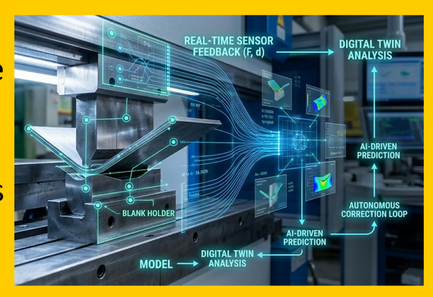


Metallography stages, FEM deformation/contact zone and model reduction strategy for model simulation

Proof to production

Our framework turns the green steel transition into a UK competitive advantage by enabling rapid validation of new products and better control of product and process variability. This helps UK manufacturing stay resilient to material and process changes while improving understanding and management of the homologation VDA test.

Agility:
Accelerated process setup brings new, high-performance components to market faster.
Efficiency:
Real-time anticipation of material behaviour reduces uncertainty and optimises yield across the supply chain.
National scale & global edge :
A standards-aligned architecture provides a scalable platform for autonomous forming, supporting the UK's circular, low-carbon industrial goals.



Refrencess

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