Plastometrex

Beyond Hardness: Mapping Yield and Work Hardening Gradients in Inhomogeneous Parts

CASE STUDY

Challenge

Manufacturing processes like hot rolling, forging, welding, and additive manufacturing inherently induce microstructural and mechanical gradients. Because these property variations often occur across small regions, standard uniaxial tensile testing is often impractical or impossible.

As a result, engineers routinely default to hardness profiling across sections to map changes. However, hardness returns only a single, scalar value that provides a measure of resistance to indentation. It provides zero direct information on yield strength or work hardening rates. Converting hardness to tensile properties via empirical relationships risks introducing large errors and can mask critical early-yielding behaviour.

When design, safety, or process modelling requires precise knowledge of how localised zones deform under load, simple hardness profiles fall short.

Objective

This case study evaluated how conventional Brinell hardness testing and Profilometry-based Indentation Plastometry (PIP testing) can characterise property gradients. The tests were performed on a cross-section of a hot-rolled high-strength steel beam, where differential cooling and localised plastic strain during rolling created significant through-thickness property variations between the edge and centre.

Testing

Sample: Hot-rolled high-strength steel beam.

Measurements: Brinell hardness measurements were carried out using a 1.0 mm diameter indenter and a load of 298 N. PIP testing was performed using a 1.0 mm diameter indenter according to ASTM E3499-25.

Method: Using PIP testing, indents were placed at 3.0 mm increments across a polished cross-section of the sample (Figure 1).

Figure 1: *A hot-rolled high-strength steel beam was PIP tested, revealing property differences between the edge and centre.*

Results

Both Brinell hardness and PIP-derived ultimate tensile strength (UTS) showed a **~30% variation** from edge to centre (Figure 2). Based on hardness alone, an engineer might conclude the material undergoes a modest decrease in performance toward the centre.

However, **PIP reveals that yield strength (YS) dropped more significantly, from ~750 MPa at the edge down to ~450 MPa at the centre:** a larger reduction that hardness testing fails to capture. Full stress-strain curves (Figure 3) show that while the edge exhibited high yield strength with limited strain hardening, the centre exhibited lower yield strength paired with substantial strain hardening capacity.

Differences in strength and work hardening will have resulted from changes in microstructure induced by gradients in plastic strain from the rolling process, as well as differing thermal history. Simple hardness testing is unable to detect the nuanced changes in properties across the beam and risks engineers drawing the wrong conclusions.

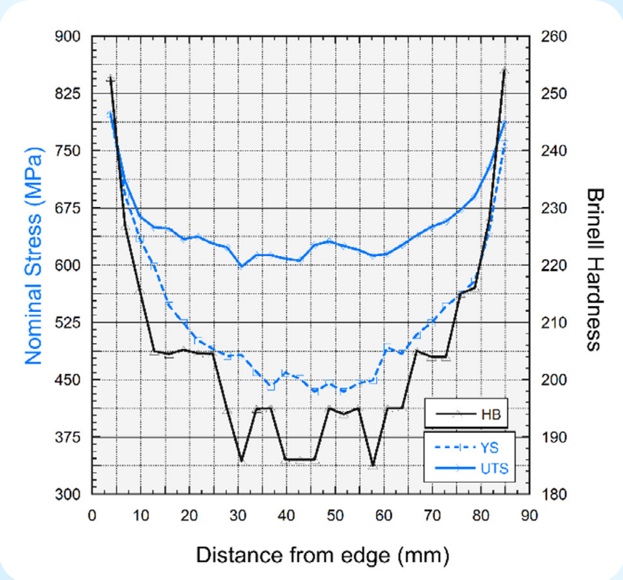

Figure 2: *Plot of both Brinell and PIP-derived ultimate tensile strength (UTS)*

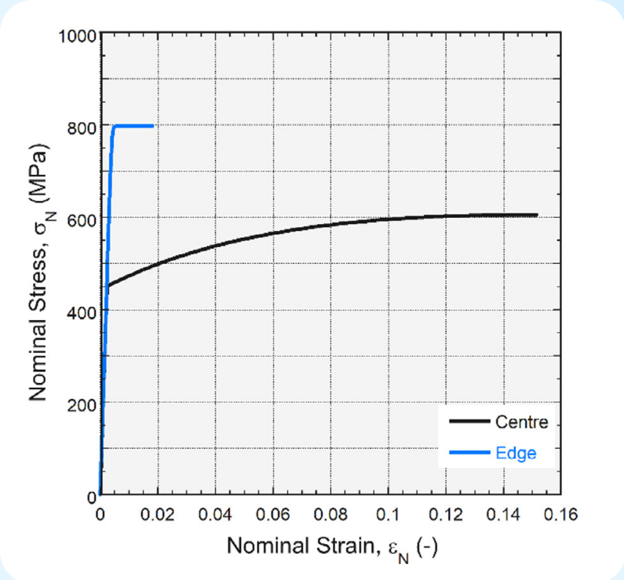

Figure 3: *Plot of full stress-strain curves from the centre and the edge of the weld*

Conclusion

While hardness testing remains a quick comparative tool, it delivers an incomplete and potentially misleading picture of material inhomogeneity. PIP delivers an ASTM-compliant method for generating stress-strain curves at high spatial resolution, giving engineers the accurate yield and work-hardening data necessary for advanced design, simulation, and process optimisation.

EXPLORE PIP

Why stress-strain matters:

Accurate FEA & Digital Twins:
Structural simulations based on converted hardness values could easily underestimate yield strengths near the centre or assume strain hardening capacity at the edge that isn't present.

Optimising Forming Processes:
Understanding true property gradients provides process engineers with richer datasets to tune deformation rates and thermal conditions.