Experimental investigation of the cyclic properties of welds in mild structural steels

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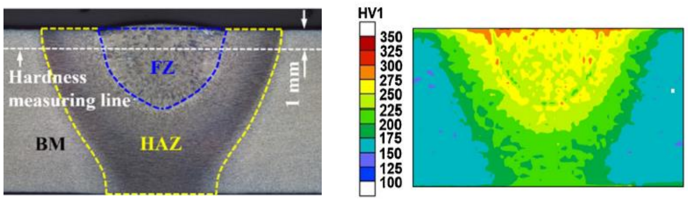
1. OBJECTIVES

- Study the behaviour of the heat affect zones (HAZ) of welds under cyclic loading typical of structural steels joints in earthquake scenarios;
- Produce physical specimens representative of HAZs for experimental testing under uniaxial cyclic loading protocols (LPs);
- Obtain parameters of HAZ metals for common material models in order to (i) compare it to base material response and (ii) for future use in numeric welded steel joint simulations.

2. MATERIALS AND METHODS

- Target material: HAZ of S355J2+N structural steel from 15mm thick plate;



Left: micrograph. Right: Vickers hardness (HV1) profile. BM - base material; FZ – fusion zone

Fig.1 - TIG welding without weld metal deposit– from Sun et al., 2019.

- Difficulty in manufacturing specimens for uniaxial tests from HAZs resulted in reproducing the base material's thermal loading during welding with a Gleeble machine in EPFL's structural engineering group (GIS);

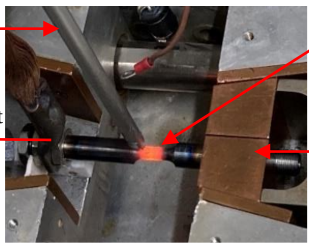


Fig.2 – Thermal loading of uniaxial specimen in Gleeble

- Various thermal loading protocols implemented in order to target the same microstructure and hardness of mild steel HAZs – cf. Fig.1;
- Performed uniaxial cyclic tests under ten LPs [de Castro e Sousa, et al., 2020]. in bespoke test-setup for HAZ and for base metal (control);

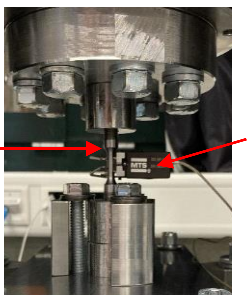


Fig. 3 – Uniaxial cyclic test-setup

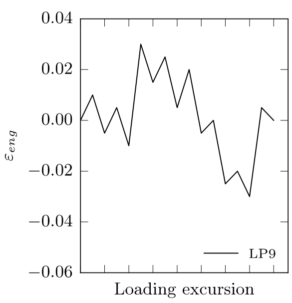
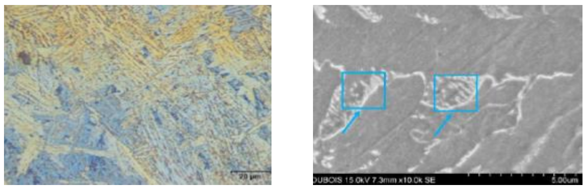


Fig. 4 – Example load protocol

- Parameters obtained by solving an inverse problem for two material models: Voce-Chaboche (VC) and Updated Voce-Chaboche (UVC) [Harloper, et al., 2021].

3. RESULTS

- Targeted microstructure (bainite) and hardness of around 210HV1 is obtained with 10° C/s cooling rate from austenitization temperature;



Left: overall bainite microstructure – optical microscopy and NITAL chemical attack.
Right: scanning electron microscopy of low bainite islands.

Fig. 5 – Gleeble-simulated HAZ metallography.

- Main experimental observations: (i) yield-plateau not present in HAZ materials, (ii) HAZs work- hardens more the base metal, and (iii) HAZ has a lower fracture strain;

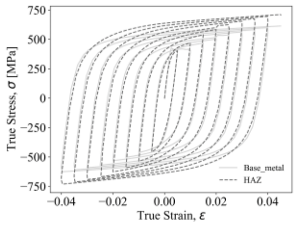


Fig. 6 – LP6 of incrementally increasing strains – Base vs. HAZ material

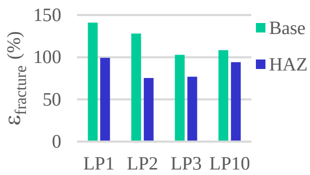


Fig. 7 – Estimated fracture strains from area reduction

- Parameters estimates for chosen material models provide good fit to test results;

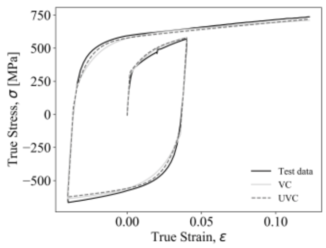


Fig. 8 – Model fit to test data: one cycle to failure test– LP3

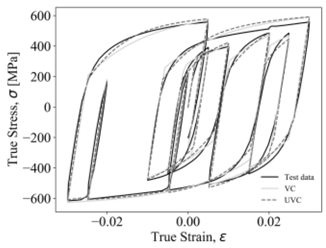


Fig. 9 – Model fit to test data: random load protocol – LP9

- VC and UVC model responses are very similar for HAZs— mostly due to the fact that HAZs do not show discontinuous yielding.

4. CONCLUSIONS

- HAZs are less ductile than base metals— a known fact which is corroborated by these experiments;
- Drop in fracture strain with material cycling shows that HAZs are as susceptible to ultra-low cycle fatigue as base metals;
- The material model parameters derived in this thesis will allow more accurate models of welded structural steel joints. This is a crucial aspect for studying the susceptibility to fracture (monotonic or cyclic) for significant strains as expected under earthquake loading.

REFERENCES

[Sun et al, 2019] - Solid-state phase transformation and strain hardening on the residual stresses in S355 steel weldments, Journal of Materials Processing Technology, 265, 173-184

[de Castro e Sousa et al., 2020] – Consistency in Solving the Inverse Problem of the Voce-Chaboche Constitutive Model for Plastic Straining, ASCE Journal of Engineering Mechanics, Vol. 146, Issue 9

[Hartloper et al.,2021] – Constitutive Modeling of Structural Steels: Nonlinear Isotropic/Kinematic Hardening Material Model and Its Calibration, ASCE Journal of Structural Engineering, Vol. 147, Issue 4