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Hydrogen Embrittlement of Automotive Ultra-High-Strength Steels – Mechanism & Minimisation

Background

Increasingly, automotive manufacturers are under commercial and legislative pressure to reduce vehicle mass, necessitating 'down-gauging' of automotive body structures, which in turn requires a greater use of Ultra-High-Strength Steels (UHSS) in place of lower-strength steels to maintain crash performance and required stiffness. UHSS are, however, particularly susceptible to a phenomenon known as 'hydrogen embrittlement' (HE) or hydrogen assisted cracking (HAC), which manifests by seemingly instantaneous mechanical failure at stress levels much lower than expected, and drastically reduces ductility of material when it has been exposed to a source of diffusible, atomic hydrogen.

This project's initial aim is to characterise corrosion characteristics for each steel based on realistic conditions, and to what degree this will induce hydrogen diffusion through each of the identified microstructures. This will, in turn, lead to determining how differences in microstructure affect absorption and diffusion of hydrogen throughout the material in static conditions, and to what extent hydrogen diffusion can affect the corrosion properties of the steels.
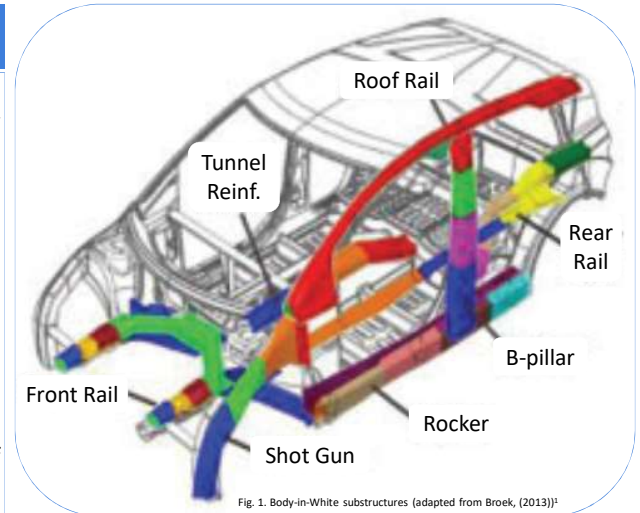

Fig. 1. Body-in-White substructures (adapted from Broek, (2013)[1])

Hydrogen Generation

Though some hydrogen may be encountered during manufacture, principal source of atomic hydrogen in automotive steels is from corrosion activity:

- It is necessary to characterise how reactive (susceptible) each steel is by performing a variety of electrochemical tests.
- Some indications that for these steels there are differences in reactivities at potentials in the range -1.09 V to -1.20 V, possibly due to differences in microstructure or chemistry.
- Use of the Scanning Kelvin Probe Force Microscope (SKPFM) will show how different phases or microconstituents react, i.e. where hydrogen will be generated.

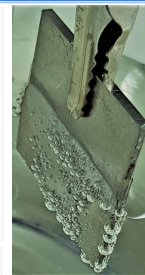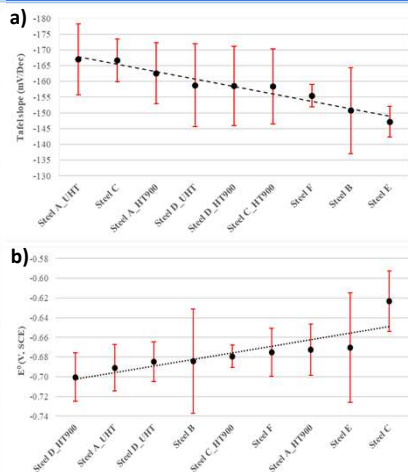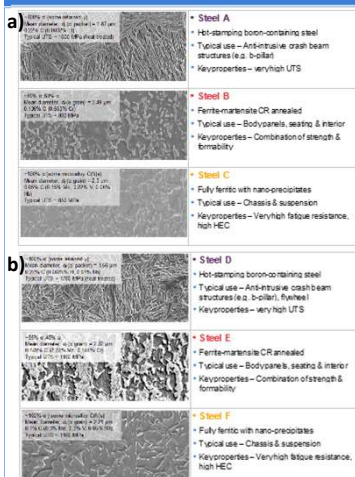Fig. 2 (above). Hydrogen being generated at surface of cathodically polarised steel.
Fig. 1 a) (top left) and b) (bottom left) Descriptions of the steels being investigated. Fig 2 a) (top centre) Average cathodic Tafel slopes, and b) (bottom centre) free corrosion potentials in aerated 3.5% NaCl solution for the steels being investigated.

The implications are that whilst there appeared to be no difference between different heat-treatments for the same chemistry, there were differences between steels of different chemistry / microstructure.

- This is the first step towards identifying characteristics that may assist in designing against hydrogen assisted/induced cracking.
- Those with a comparatively 'accelerated' hydrogen generation (in this case at potentials comparable to the anodic dissolution of zinc), are likely to reach a critical hydrogen concentration (C_H) to induce hydrogen cracking processes more quickly, under the given conditions.

## Effect of Permeated Hydrogen on Corrosion Properties

It can be seen that pre-charging a specimen with hydrogen to one surface will affect the corrosion characteristics on the opposite surface:

- During hydrogen permeation experiments, it is assumed for thin membranes gauge is less than or equal to 0.2 times the charging area[2], hydrogen diffusion is one-dimensional.

To back up scanning Kelvin probe (SKP) work previously undertaken by Williams et al (2013)[3], and follow-up study using the scanning vibrating electrode technique (SVET), a time-lapse photography technique was used to demonstrate the linearity of hydrogen diffusion, and the preferential corrosion that it can induce.

- Early indications imply a hydrogen effect in accelerating a breakdown in passivity at lower potentials. This in turn has the potential to exacerbate hydrogen generation during corrosion, as lower pH in pit cavities will favour a hydrogen evolution reaction, expediating time to C_H.

Fig. 3 a) Pure Fe 0.1 mm gauge foil masked off with 5490 PTFE tape, leaving adjoined circles to be exposed to 0.1 M Na_2SO_4 electrolyte for hydrogen charging at -20 mA/cm² for 20 minutes; b) to e) time-lapse photographs of reverse face of Fe foil with 100 mm² exposed immediately after hydrogen charging to 0.1 M NaCl electrolyte and allowed to freely corrode, where b) t = 0 min, c) = 30 min, d) = 1 hour, and e) = 2 hours after immersion; f) reverse image of exposed hydrogen charging area to demonstrate correspondence between hydrogen charging and corrosion.
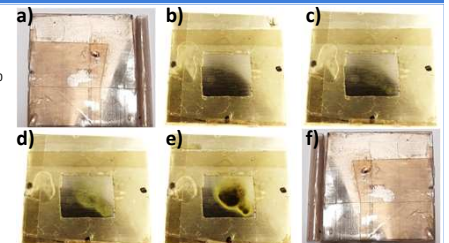
References
1. Broek CT. FutureSteelVehicle: leading edge innovation for steel body structures. Ironmaking & Steelmaking. 2013;39(7):477-92.
2. Barrer R, Barrie J, Rogers M. Permeation through a membrane with mixed boundary conditions. Transactions of the Faraday Society. 1962;58:2473-83.
3. Williams G, McMurray HN, Newman RC. Surface oxide reduction by hydrogen permeation through iron foil detected using a scanning Kelvin probe. Electrochemistry Communications. 2013;27:144-7.

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M2A
MATERIALS AND MANUFACTURING ACADEMY

UNDEB EWROPEAIDD EUROPEAN UNION
Llywodraeth Cymru Welsh Government
Cronfa Gymdeithasol Ewrop
European Social Fund

EU Funds: Investing in Wales

JL3 Update Tafel / Ecorr
graphs, add micrographs
and stats (some EBSD?).
describe implications

James Lelliott, 29/01/2019