A new hydrogen extraction method based on understanding interstitial redistribution

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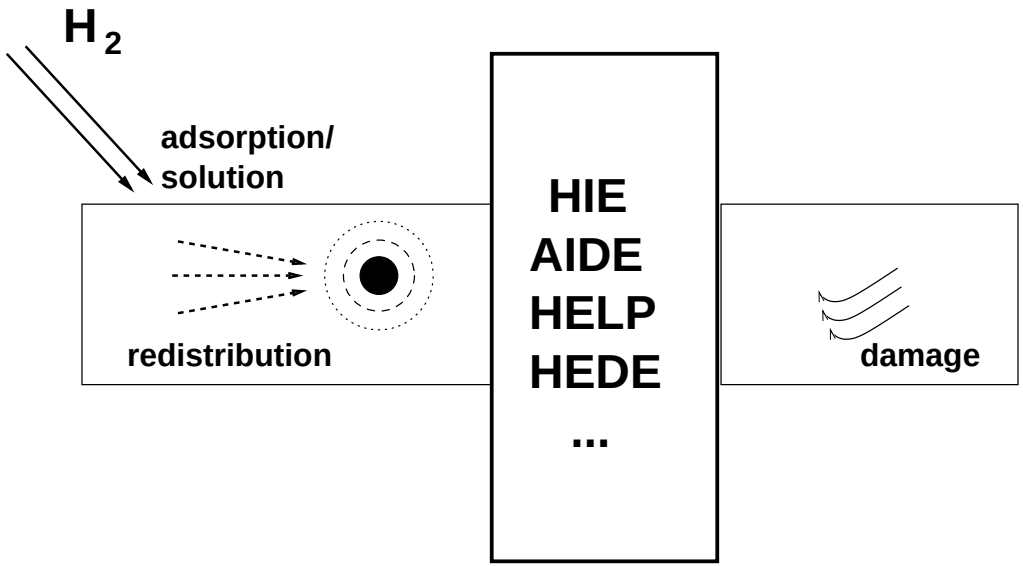
Hydrogen Embrittlement

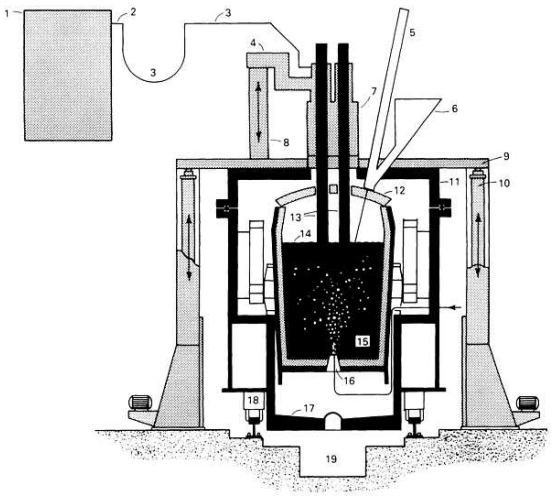
Hydrogen Embrittlement: Complex phenomenon involving multiple & competing mechanisms



But it all starts with hydrogen

- *HIE : Hydride-induced embrittlement (second phase)*
- *AIDE: Adsorption-induced dislocation-emission,*
- *HELP: Hydrogen enhanced localised plasticity*
- *HEDE: Hydrogen enhanced decohesion mechanism*
- *Macroscopic damage: microcracking, flaking, surface defects, porosity, et c.*

Methods to prevent hydrogen embrittlement:



- At the design stage (alloy selection)
- Extraction from liquid metal during refining
  - Standard: (*i.e.* AOD):
    $[H] \approx 1.5 - 2.0$ppm (LOW YIELD)
  - Vacuum degassing:
    $[H] \approx 0.5 - 1.5$ppm (HIGH COST)
- Extraction by treating after cooling:
  - Baking treatment (NOT ALWAYS EFFECTIVE)

A new method:

Extraction by **controlled directional cooling**
(PCT patent WO/2010/097755)

Development of a new hydrogen extraction method

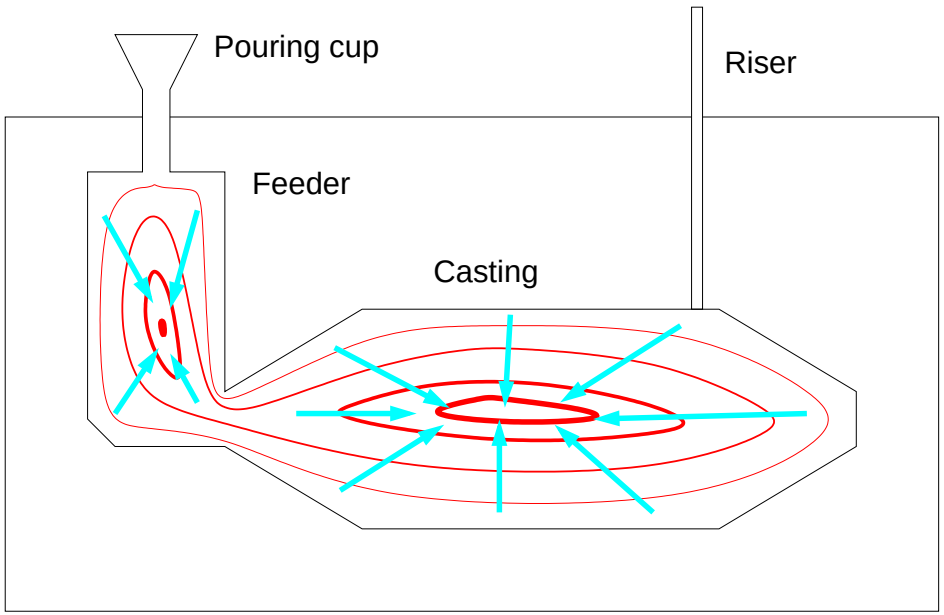
"Understanding hydrogen redistribution during steel casting, and its effective extraction by thermally induced up-hill diffusion"
D. Gaude-Fugarolas, in: Journal of Iron and Steel Research International 18 supl.1.1 (2011) 159–163.

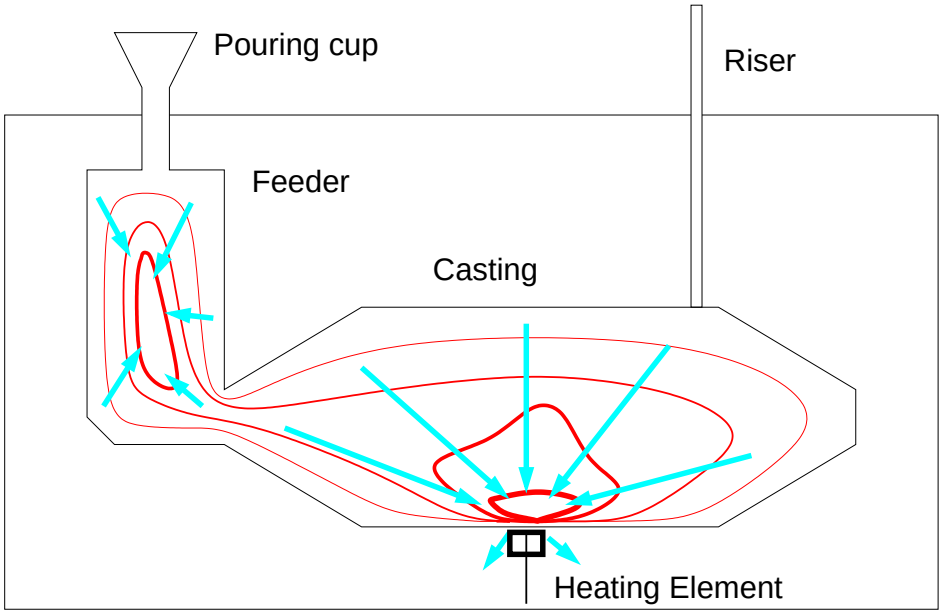
Also at proceedings: **High Strength Low Alloy (HSLA2011) International Conference, Beijing, China, 2011**.

A new hydrogen extraction method

Standard casting operation: The natural flux of interstitial elements (like **hydrogen**) creates enriched regions at the core of the piece

However, by using a modified casting operation with **directional cooling** and a controlled thermal gradient is possible to eliminate hydrogen from the piece without need for vacuum casting or further treatments





Comparison in H redistribution during cooling

Cooling a 25cm thick plate with 2ppm H:

Slow cool	Some H reduction ($\approx$ 25%) No concentration peaks Low supersaturation Long time: 42 hours
Fast cool	No H reduction ($\approx$ 1%) Severe concentration peaks Severe supersaturation Short time: 1.5 hours
Directional cool (**Patented**)	Large H reduction ($\approx$ 50%)* Minor concentration peaks* Low supersaturation* Short time: 2.5 hours

* Optimise the treatment to each component by modifying cooling severity and treatment time

Conclusion

A new method enables to reduce hydrogen in an alloy via the use of imposed temperature gradients. (**PCT patent WO/2010/097755, already awarded in US, China and Spain. In process at European and Brazil POs**).

- *Example of application:* Standard process casting a large component. Let's consider a x% of risk of cracking. By using this method, it is possible to reduce this risk without need to use vacuum casting.
- *Example of application:* During vacuum casting, final concentrations of 1 ppm hydrogen are usual. For a very large component, this concentration still produces cracking. The method presented can be combined with vacuum casting to reduce H content further.
- *Example of application:* In a complex component, hydrogen damage tends to appear in a specific region of the component. By applying this method to avoid H in that region, hydrogen supersaturation is removed and embrittlement avoided.
- Additionally, with the models developed during this project it is possible to predict when and where hydrogen damage will occur, allowing to take action to prevent it.
- Better understanding of hydrogen redistribution and trapping also allows to design treatments (*i.e.* baking) that actually work.

Reduction of hydrogen embrittlement risk & Cost reduction & Quality increase & Better process control

Conclusion

Thank you for your attention!!

For more information on this method or on the possibilities of this model, please visit (or email):

primeinnovation.net

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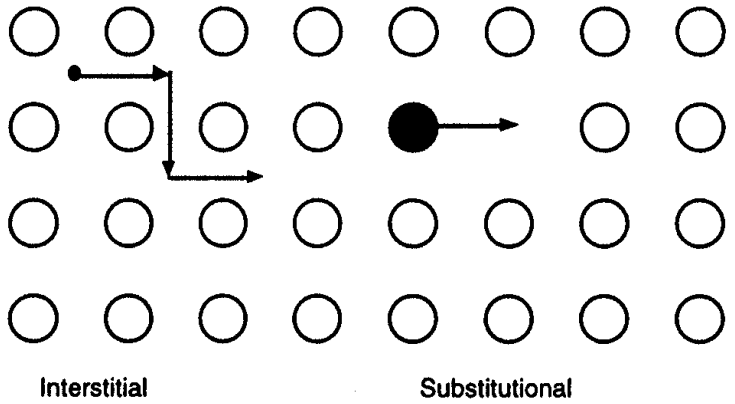
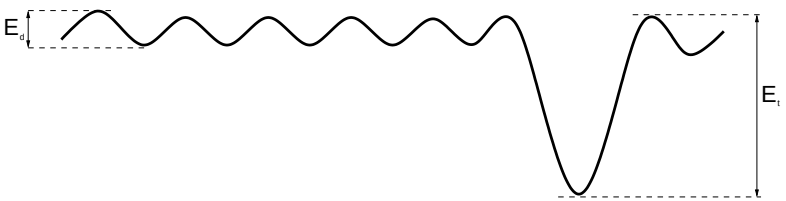
Understanding hydrogen redistribution: The physical model used

Hydrogen diffusion described as **random walk** of interstitial elements, driven by **chemical potential** gradient

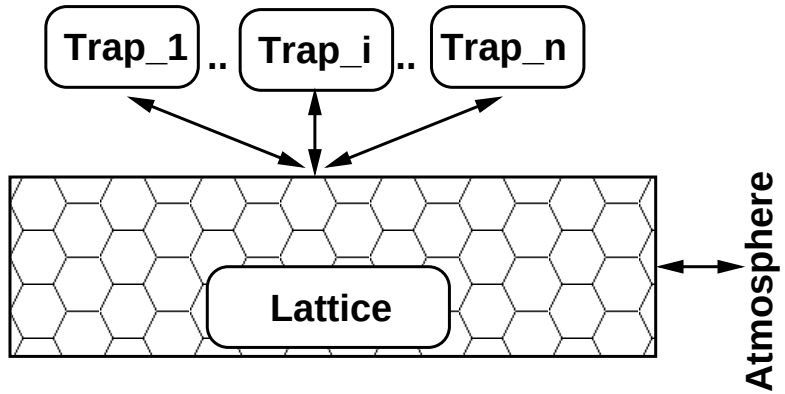




Each trap type characterised by its characteristic release energy barrier

Interaction of each of the trap sites with lattice

Exchange with atmosphere at free surfaces: local equilibrium across the surface (Sievert's law)



Further results of this project: Analysis of Casting

"Understanding hydrogen redistribution during steel casting, and its effective extraction by thermally induced up-hill diffusion"
D. Gaude-Fugarolas, in: Journal of Iron and Steel Research International 18 supl.1.1 (2011) 159–163.

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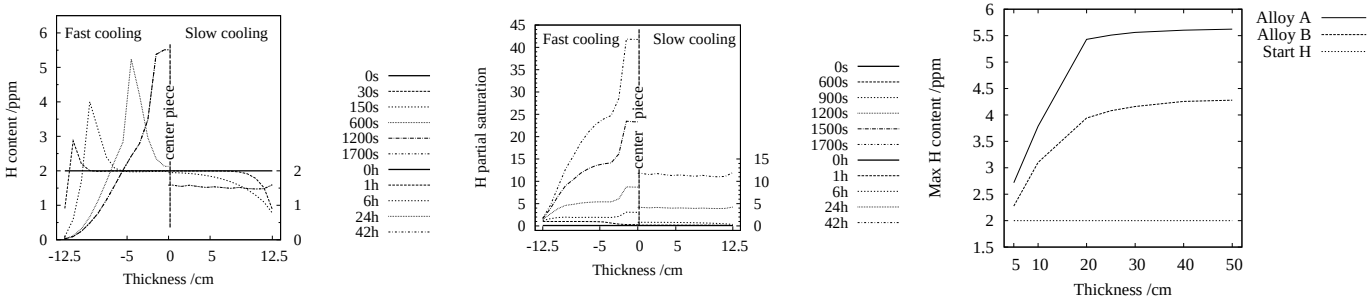
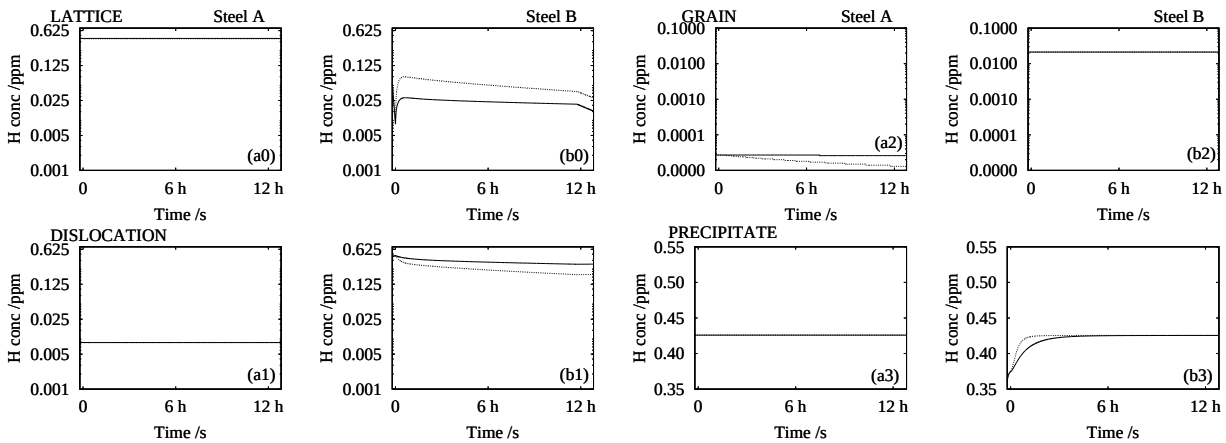


Further results of this project: Analysis of Baking

"On the effectiveness of baking as hydrogen embrittlement reduction treatment"
D. Gaude-Fugarolas, in: Proceedings of METAL2014, 21-23 May, Brno, Czech Republic, 2014.



Further results of this project: Prediction of hydrogen damage

"Prediction of hydrogen damage"
D. Gaude-Fugarolas, in: Proceedings of METAL2015, 3-6 June, Brno, Czech Republic, 2015.