Microstructural Influence on Hydrogen Embrittlement in Advanced High-Strength Steels

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The effects of hydrogen embrittlement were examined in martensitic (M) and dual phase (DP) advanced high strength steels via several mechanical and characterization tests after artificially charging them with hydrogen. Inclusion analysis showed that the martensitic samples had a greater area of inclusions within its microstructure, which were visible in the fracture surfaces. During tensile tests, the charged and uncharged dual phase and martensitic samples all reached a UTS and began necking before fracture, but both charged samples showed less thickness reduction between the UTS and fracture. Postionon annihilation also showed a greater effect of hydrogen charging in M, with the lifetime difference being 6.3 and 5.0 ps for r1 and r2 between charged M and uncharged M, respectively, while the DP differences were 4.4 and 4.5 ps for r1 and r2, respectively. This indicated an increase in trapping site volumes within the inclusion sample.

Automated Steel Cleanliness Analysis Tool (ASCAT)
ASCAT is used to measure the types, amount, and size of inclusions within steel samples. Inclusions can act as hydrogen trapping sites and increase the solubility of hydrogen into the sample, thereby increasing susceptibility to hydrogen embrittlement.

Thermal Desorption Analysis
Thermal Desorption Analysis (TDA) was used to measure the hydrogen levels in the samples. Acquired from ArcelorMittal.

Table 1: Chemical compositions of ArcelorMittal’s M1100 and DP1180 AHSS (seen in Figure 1) were analyzed.

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
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<tbody>
<tr>
<td>M1100</td>
<td>0.12</td>
<td>0.45</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DP1180</td>
<td>0.18</td>
<td>2.4</td>
<td>0.60</td>
<td>-</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Figure 1: Chemical compositions (all in wt%) and microstructure images of M1100 (left) and dual phase DP1180 (right) advanced high-strength steels.

Project Goal: The goal of this project was to use various characterization and mechanical tests to determine which material is less susceptible to hydrogen embrittlement.

Artificial Hydrogen Embrittlement
Atomic Hydrogen Charging: Hydrogen embrittlement can be simulated through artificially causing hydrogen diffusion via an electrolytic cell. A current of 10mA is passed through an acidic solution with the steel sample as the cathode. This caused the hydrogen to dissociate at the surface and diffuse into the sample due to the concentration gradient. The tensile dogbones (gauge length: 80x12x2 mm) and the smaller coupons (25x25x2 mm) were charged for one hour.

Thermal Desorption Analysis
Thermal Desorption Analysis (TDA) was used to measure the amount of hydrogen trapped within the microstructure of the steel samples. Three DP and three M samples were tested at ArcelorMittal and each had a minimum of 0.60 ppm diffusible hydrogen when heated to 250 °C. This proved that the charging method was functional.

ASTM E45
ASTM E45 allows for a simple evaluation of inclusions to determine the cleanliness of the steel. The results show the presence of nitride inclusions. Elements such as Ti, Zr, and Fe form a stable compound with nitrogen. FeN is an especially undesirable inclusion because it causes precipitation of fine dispersed non-metallic particles along grain boundaries which weaken the bonding of grains, reducing the plasticity[1]. The dual phase steel presented a higher number of these inclusions.

Conclusions
Based on the fracture surface microscopy, it is evident that both samples were embrittled by hydrogen. While it is challenging to quantify how much the samples were embrittled from these images, the PALS data showed that the martensitic steel was more affected by hydrogen embrittlement based on positron lifetime differences. One possible explanation is that the martensitic steel had a greater area of inclusions, according to the ASCAT and ASTM E45 results. A greater number of inclusions, especially oxides, meant that there were a greater amount of irreversible hydrogen trapping sites.

In conclusion, the data showed that both the martensitic and dual phase AHSS samples were affected by hydrogen embrittlement after the materials’ ultimate tensile strengths; however, according to PALS data, the dual phase steel was less susceptible.

Acknowledgments
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