Hydrogen Embrittlement in As-Cast Slabs of Ultra High Strength Steel

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The aim of this project was to investigate the effects of hydrogen embrittlement in ultra-high strength steels produced by ArcelorMittal. To simulate its presence, hydrogen was electrolytically introduced to Charpy bars provided by ArcelorMittal. The initial focus of the project was to characterize the impact energy of hydrogen-charged steel samples at elevated temperatures. Subsequent foci included flexure testing, fractography, and microstructure characterization of these steels. Noticeable failure differences between alloys was observed using 3-point bend testing. This result verifies a presence of hydrogen and the role it plays in fracture.

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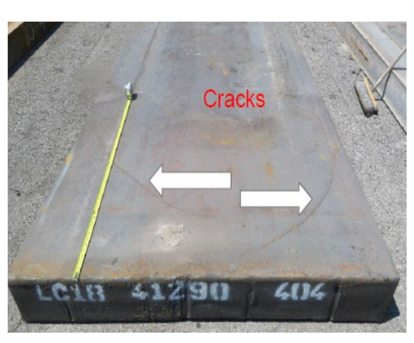
ArcelorMittal

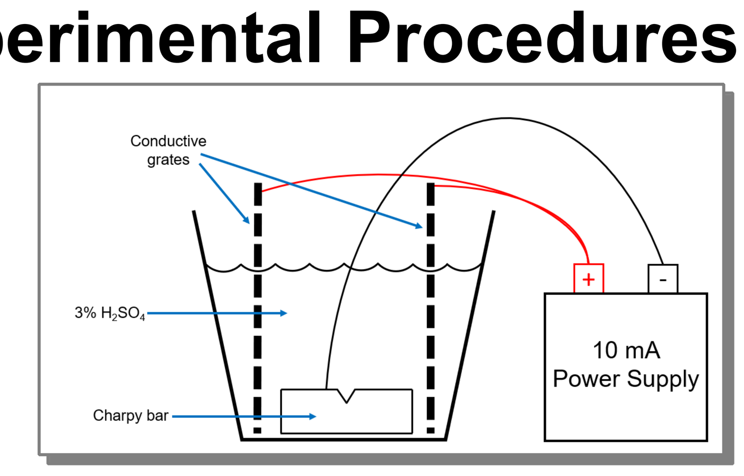
Project Background

ArcelorMittal processes bulk, as-cast slabs of high strength low alloy steel, specifically 100XF grades 302, 304, and 404. The 302 grade is microalloyed with titanium and niobium. The 304 grade possesses the same composition as 302 but with the addition of being microalloyed with molybdenum. The 404 grade also contains the components of 302 but microalloyed with chromium. These slabs are 10" thick, and are cracking while sitting in the steel yard or during transportation. These cracks are preventing processing for manufacturing purposes. These grades are experiencing cracking due to the phenomenon of hydrogen embrittlement.

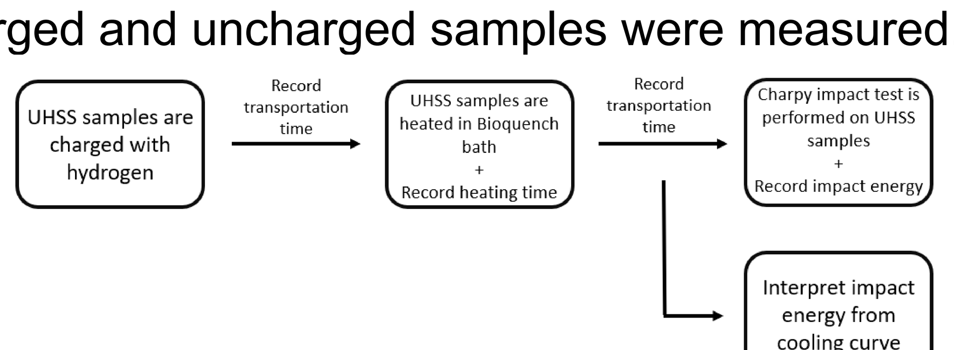


The image above and the image to the right indicate where the cracking is occurring in these slabs. The cracks on the image to the right are highlighted by the orange lines.

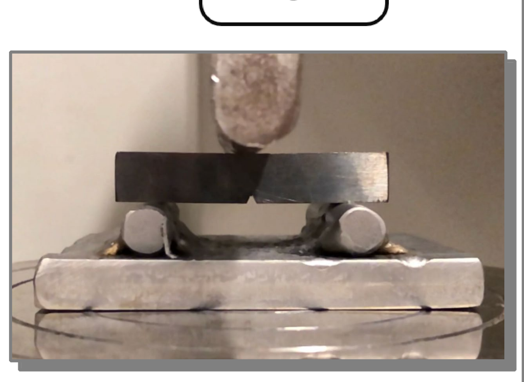
Experimental Procedures



Charged and uncharged samples of 302 and 304 were heated in an oil bath to 200℃ and charpy tested. This temperature did not reach the ductile-to-brittle transition temperature and the fractures were brittle. No meaningful differences between the charged and uncharged samples were measured.



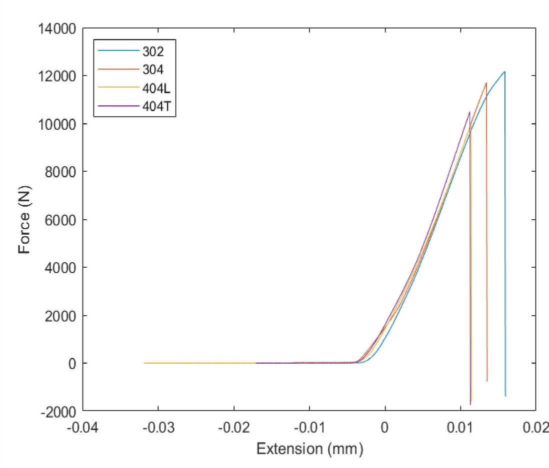
In the spring semester, the mechanical testing procedure was changed from Charpy impact testing to 3-point flexure testing.

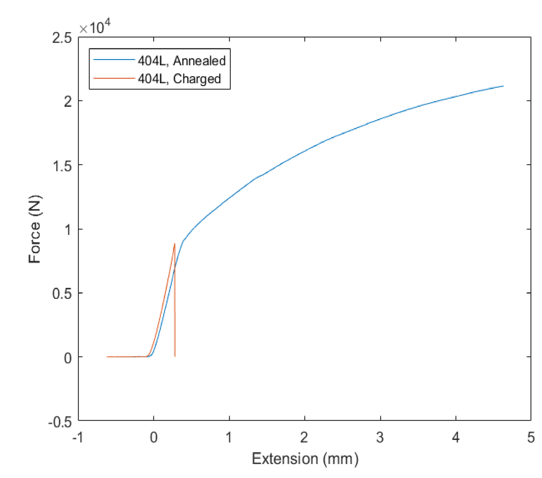


The 3-point bend testing procedure allowed for a slower strain rate. The samples were loaded with 40 mm span and strained at 0.25 mm/min until failure.The samples were tested according to the table to the right. The samples were then analyzed utilizing optical microscopy and the Phenom desktop SEM to analyze fracture surface and microstructure.

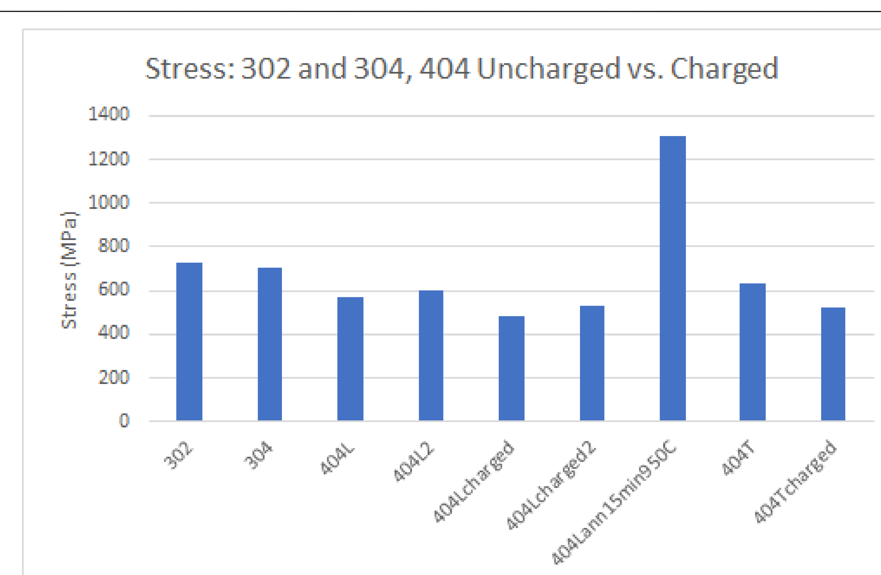
3-Point Bend Testing Conditions	
404L	404T
1. As-Cast	1. As-Cast
2. Charged	2. Charged
3. Heat treated at 950℃ for 15 minutes	3. One sample heated @ 600℃ for 30 minutes and a second sample heated @ 375℃ for 30 minutes. *Heating done according to TDA desorption peaks

Results

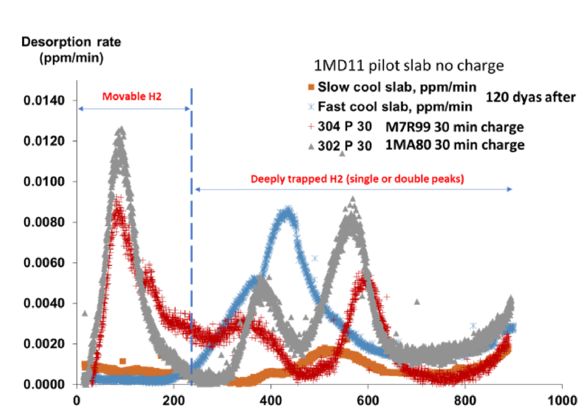




As-cast UHSS samples in 3-point flexure display brittle, linear-elastic behavior at room temperature. Samples fracture abruptly, with no prior macroscopic deformation. Beginnings of yield can be seen just before failure in 302 and 304 steels. This can be seen by a small shear lip, microvoid coalescence, directly below the notch. Fully annealed samples display much more ductile behavior.

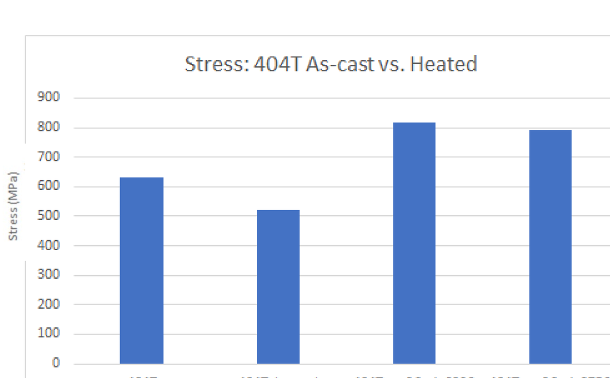


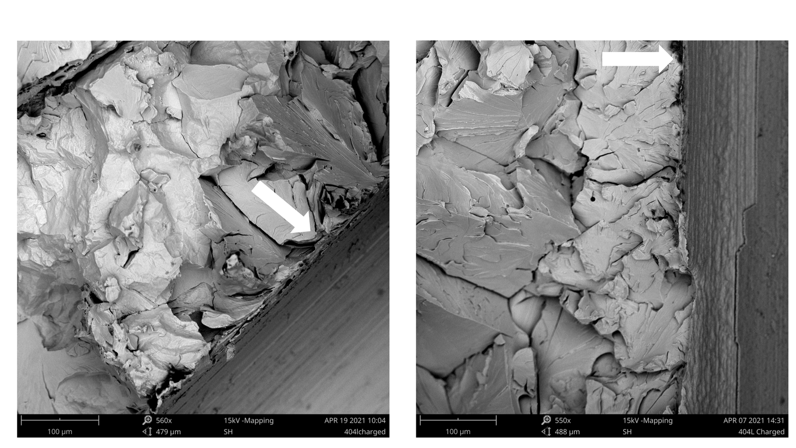
The 302 and 304 steels failed at higher stresses than 404 steels. On average, charging samples with hydrogen was found to decrease the failure stress. Heat treating 404L steel at 950℃ for 15 minutes significantly increased the fracture stress and changed the fracture behavior from brittle to ductile.



Movable hydrogen inside UHSS samples is released by heating to low temperatures. Immovable, or trapped hydrogen is released at higher temperatures. Desorption peaks for trapped hydrogen are seen at 375℃ and 600℃ in 302 and 304 steel.

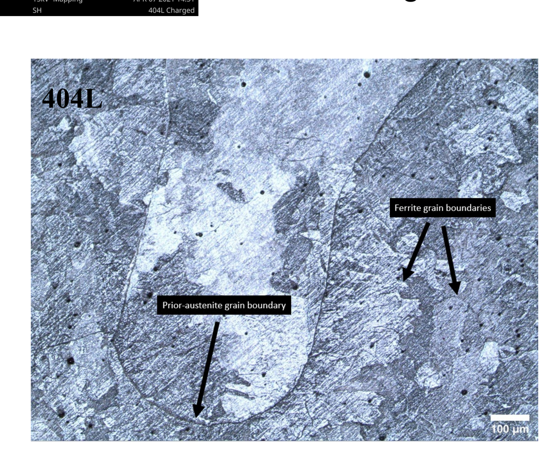
Heating 404T steel to 375℃ and 600℃, corresponding to thermal desorption of trapped hydrogen, prior to flexure testing resulted in an increase in failure stress. This indicates that immovable hydrogen is trapped in the microstructure of 404 steels, and can move via high temperature or high stress

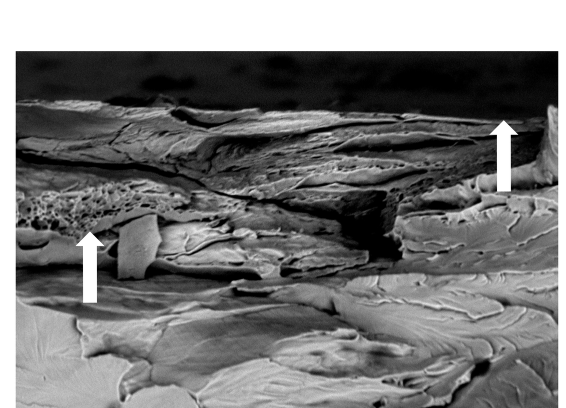




SEM analysis of the fracture surface of 404 steels shows intergranular fracture between grains as well as cleavage through grains. The arrows shown indicate the notch region.

The prior austenite grain size was found to be large compared to the ferrite in the as-cast slabs using optical microscopy





SEM image of the fracture surface showing a small shear lip that formed directly below the notch. The region of microvoid coalescence is marked in the figure by the arrow on the left and the notch is marked by the arrow on the right.

Discussion

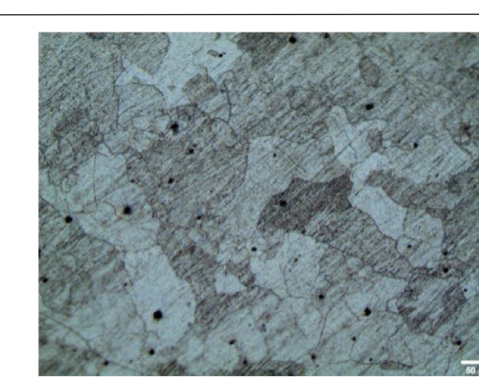
3-point Flexure Testing

The Charpy testing performed during the fall semester yielded results that were inconclusive because of the high strain rate. The results showed that 302, 304, and 404 steels fail with brittle behavior in both charged and uncharged conditions. For the 3-point bend tests with a slow strain rate, discernable results were found between alloy grades.

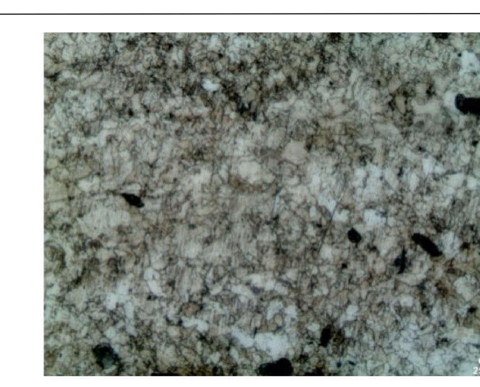
SEM images of broken 3-point bend specimens show intergranular fracture, cleavage, and microvoid coalescence on the fracture surface at the notch in 404 samples.

The 302 steel was found to have a higher failure stress than 304 and 404 steels. Charging the 404 samples resulted in a decreased amount of stress required before failure occurred, indicating hydrogen affects the strength of the steel.

Heating the 3-point bend specimens of 404 steel to the hydrogen desorption peaks led to an increase in the failure stress, a potential result of releasing hydrogen trapped in the metal prior to mechanical testing.



The as-cast microstructure of the 404 steel slab showing a large grain size (OM).



Microstructure after heating to 950℃ for 15 minutes then air cooled showing a fine grain size (OM).

Heating the 3-point bend specimens of the 404 steel to 950℃ (austenite) and cooling produced a fine grain size that resulted in ductile behavior upon flexure testing.

Conclusions & Recommendations

It was determined that 3-point bend testing yielded significantly more useful results that Charpy testing. This is because of the lower strain rate that the 3-point bend testing provided. From the fracture surface analysis we discovered that the samples experienced mostly cleavage but also showed signs of intergranular fracture as well microvoid coalescence.

Based on these conclusions we would recommend to ArcelorMittal that they utilize 3-point bend testing for further testing. 3-point bend testing yielded results that indicated a noticeable difference between alloy grades and verified the role that hydrogen plays in fracture. Lastly, additional 3-point bend tests should be conducted to gather a large data set for each steel grade.

Acknowledgements

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