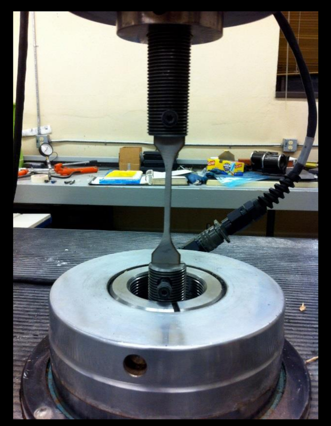
Strain Rate Effects for Hydrogen Embrittlement of 304 Stainless Steel



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Problem / Question

Can strain rate effects on the tensile strength of hydrogen-exposed 304 stainless steel be detected?

Project Overview

Three different strain rates were used to tensile test 304 stainless dogbone test specimens. Previous work by other researchers, at Gonzaga and other institutions, have shown that exposure to gaseous hydrogen affects the strain rate dependence of tensile strength. Exposure to one atmosphere of gaseous hydrogen for a one-week duration may decrease the tensile strength at low strain rates (e.g. 0.016in/min). The current work is based on performing tensile tests at the low strain rate as well as at strain rates one order of magnitude above (e.g. 0.15 in/min) and below (e.g. 0.002 in/min). For the low strain rate both exposed and unexposed samples are tested while the lowest and highest strain rates only use unexposed specimens. The new data will be compared to previous research results.

TABLE 2.5

Approximate Range of Values for *C* and *m* in Eq. (2.16) for Various Annealed Metals at True Strains Ranging from 0.2 to 1.0

Material	Temperature, °C	*C* psi × 10^3	*C* MPa	*m*
Aluminum	200–500	12–2	82–14	0.07–0.23
Aluminum alloys	200–500	45–5	310–35	0–0.20
Copper	300–900	35–3	240–20	0.06–0.17
Copper alloys (brasses)	200–800	60–2	415–14	0.02–0.3
Lead	100–300	1.6–0.3	11–2	0.1–0.2
Magnesium	200–400	20–2	140–14	0.07–0.43
Steel				
Low carbon	900–1200	24–7	165–48	0.08–0.22
Medium carbon	900–1200	23–7	160–48	0.07–0.24
Stainless	600–1200	60–5	415–35	0.02–0.4
Titanium	200–1000	135–2	930–14	0.04–0.3
Titanium alloys	200–1000	130–5	900–35	0.02–0.3
Ti-6Al-4V*	815–930	9.5–1.6	65–11	0.50–0.80
Zirconium	200–1000	120–4	830–27	0.04–0.4

* at a strain rate of $2 \times 10^{-4} s^{-1}$.

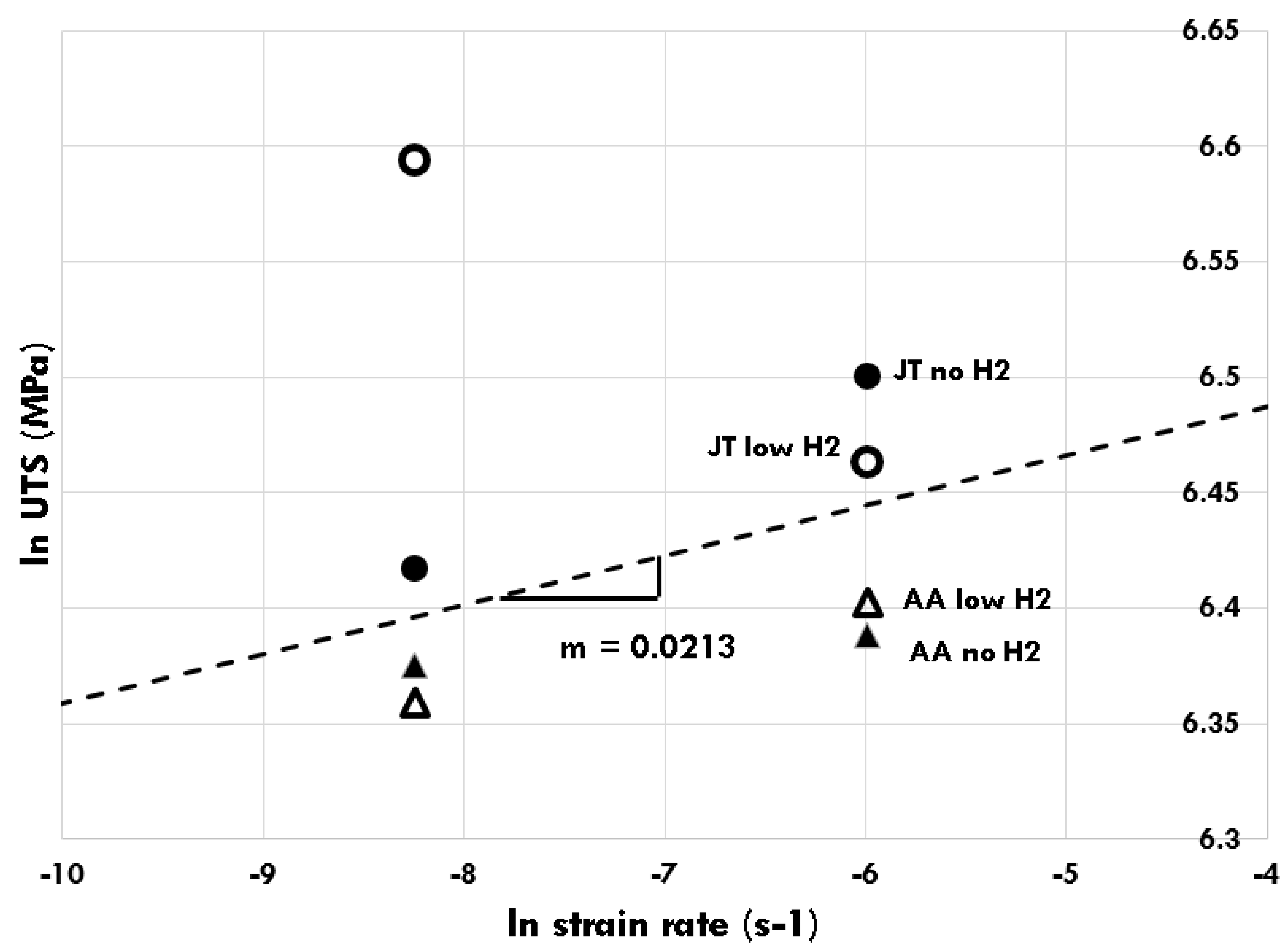
Note: As temperature increases, *C* decreases and *m* increases. As strain increases, *C* increases and *m* may increase or decrease, or it may become negative within certain ranges of temperature and strain.

Source: After T. Altan and F.W. Boulger.

Procedure

Dogbone specimens were plasma cut from sheets of 304 stainless steel. The specimens were exposed to gaseous hydrogen or were unexposed. The gaseous exposure conditions included either 138 MPa gaseous hydrogen pressure exposure (at Sandia), or 1 atm gaseous hydrogen exposure (at GU). Specimens were pulled to failure at one of three different strain rates: 3.8 mm/min, 0.4 mm/min or 0.05 mm/min. To gage length value that was used to calculate elongation at failure was 2.54 cm.

Plotting ln strain rate as a function of ln UTS allows for calculation of strain rate sensitivity exponent, m. The calculated value of m using data from Anderson and Tatka, for no hydrogen exposure of 304 stainless, is m=0.0213. Comparing data from Kalpakjian and Schmid shows this to be a reasonable value at room temperature



Preliminary Results

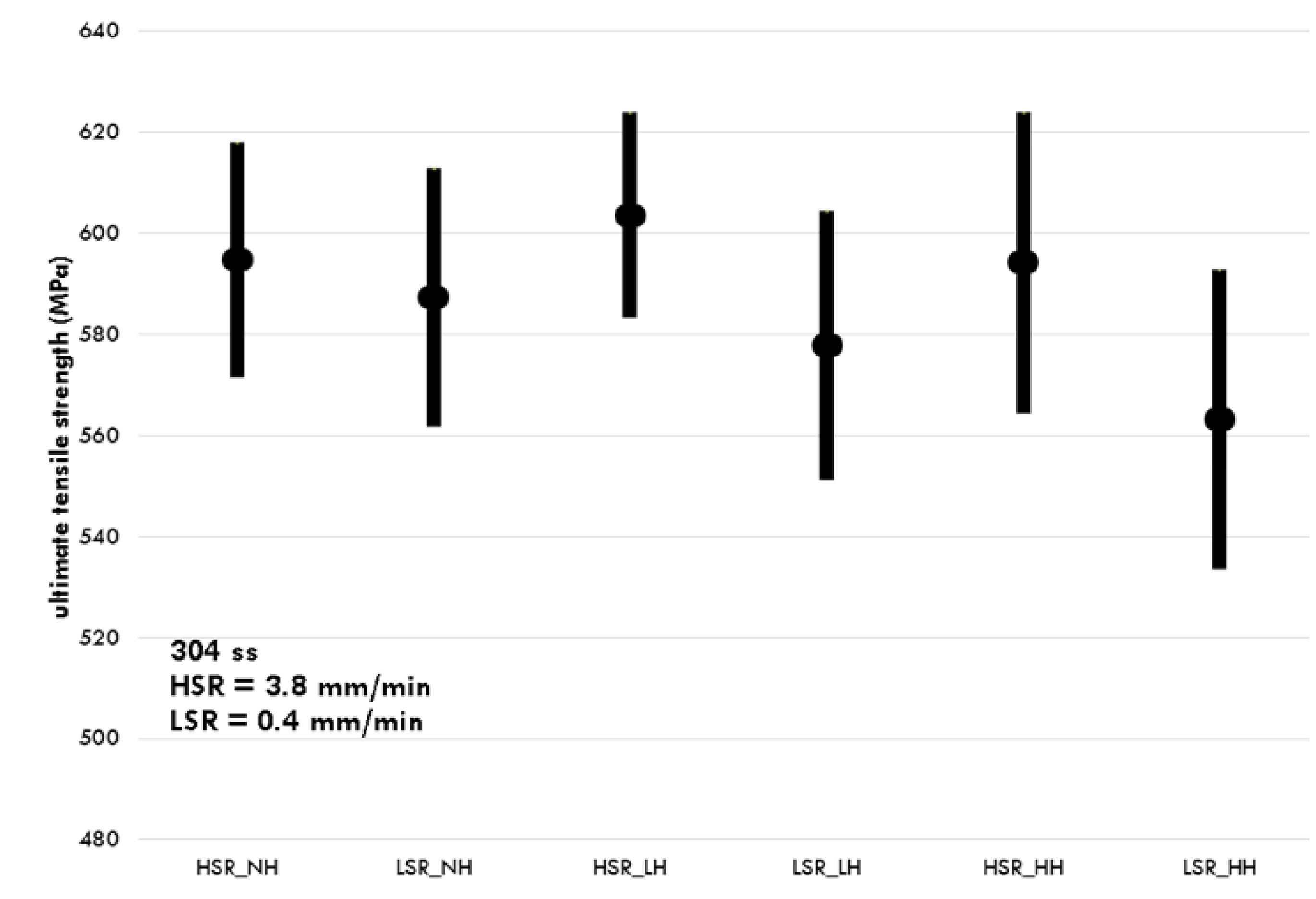


Figure 2 shows ultimate tensile strength data for 304 stainless steel specimens that were tested at two strain rates. The abscissa axis indicates the strain rate and hydrogen exposure conditions. The dot in the middle of each vertical bar on the graph is the average tensile strength for the samples that received the given strain rate and hydrogen exposure treatment. The length of the bar indicates plus or minus one standard deviation from the mean.

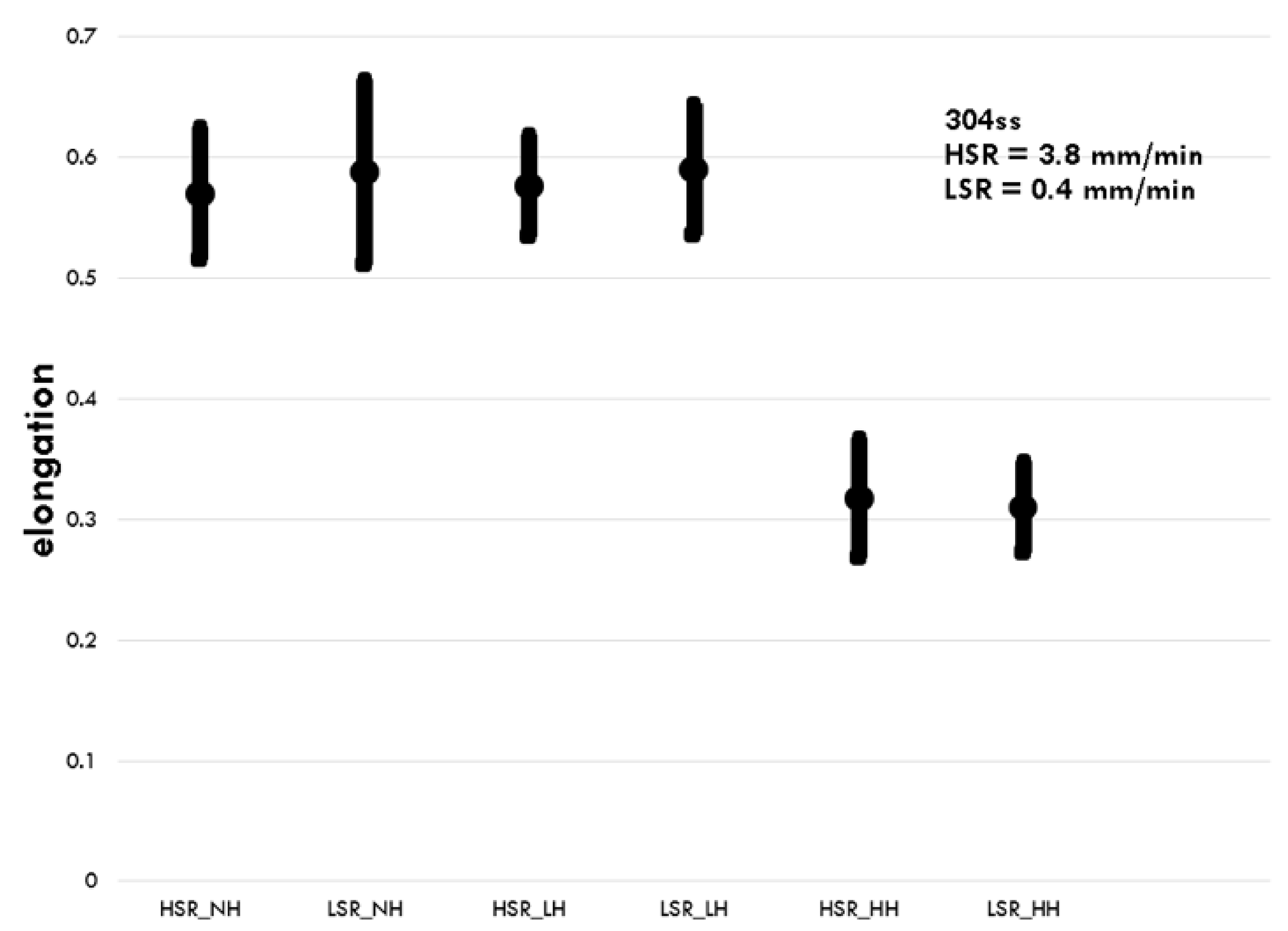


Fig. 3 Elongation for 304 stainless tensile specimens for three different hydrogen exposure levels, tested to failure at two different strain rates. The data shows that the elongation of the supersaturated specimens (aka 'high hydrogen') is lower than that of the other exposure conditions (no hydrogen and low hydrogen).