Mitigation of High Temperature Hydrogen Attack

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Introduction

- Steels in high temperature (>250^{O}C)-hydrogen environments suffer a loss in mechanical properties in a sudden behaviour after a long incubation period.
- Hydrogen reacts with carbon to form methane bubbles at grain boundaries.
- The damage starts off at microscopic level and it cannot be detected by Non Destructive Techniques until it reaches a point where the damage is sudden leading to decreases in strength, toughness and ductility.

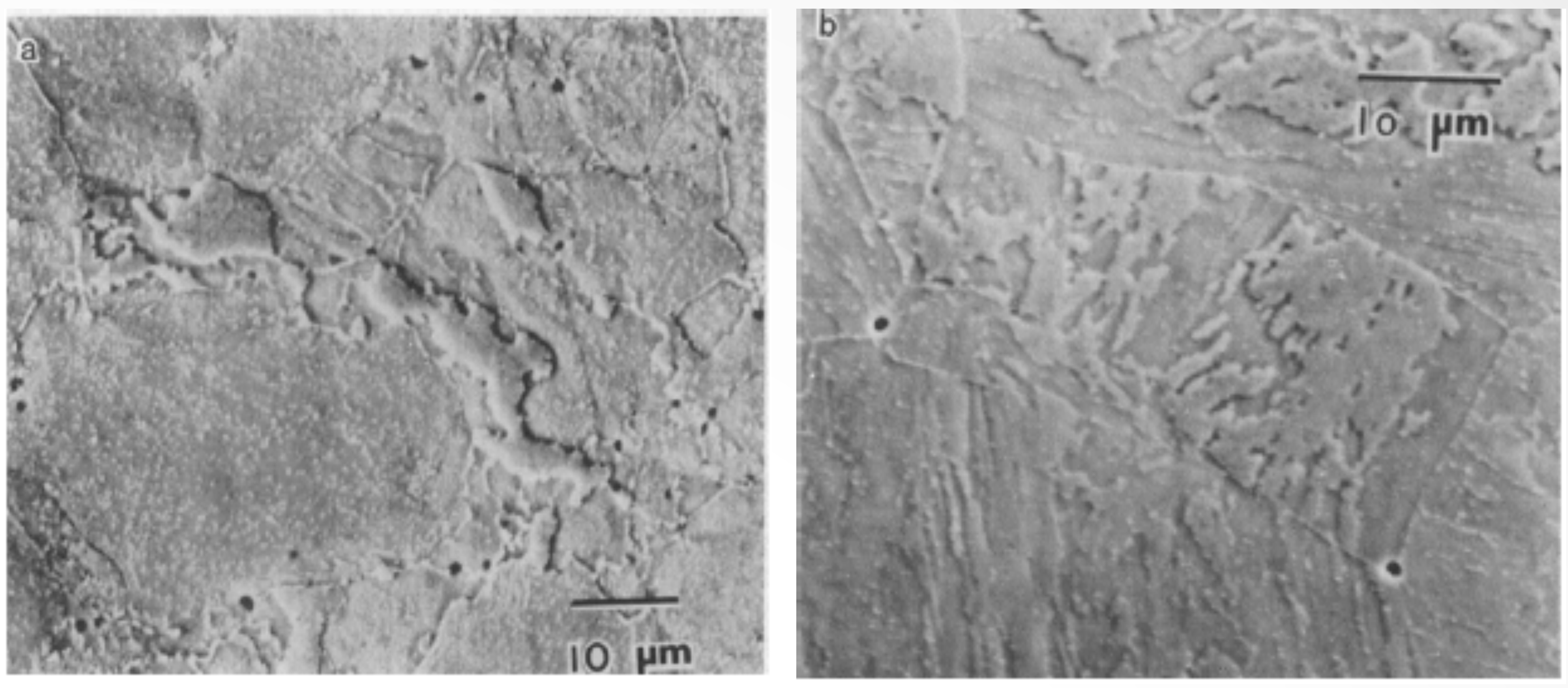

Figure 1(a,b) : Scanning Electron Micrographs showing bubbles at grain boundaries.

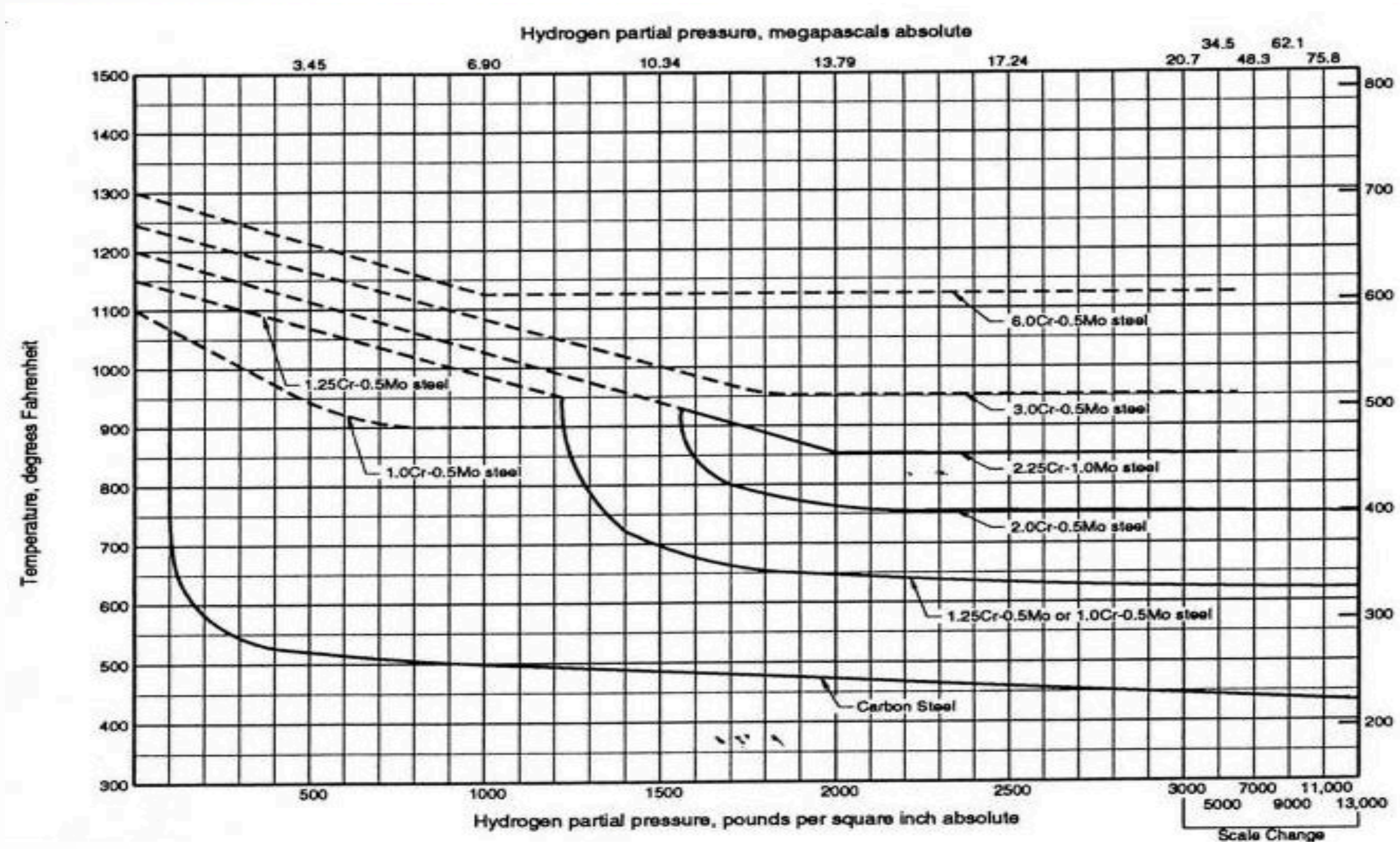

Figure 2: Nelson Curves.

Current Practice Against HTHA

- Steels should be used at the temperature-hydrogen pressures ranges shown in Nelson Curves (API 941).
- An unfortunate incident occurred in Tesoro Refinery in 2010 despite the steel being operated in the safe region implied in the Nelson Curves.
- However, the incident triggered that steels may suffer High Temperature Hydrogen Attack.

Possible assurances

- Steel with **no free carbon that hydrogen can react with to form methane.**
- Increasing **the Chromium content** in the steel can be a solution, but needs optimum alloy design.

Factors to consider

Composition

- Important elements in the composition would be:
  - **Carbon, which would favours decohesion.**
  - **Carbide formers, e.g. Cr, Mo, Nb, V and Ti.**
- **Complete precipitation of stable carbides at grain boundaries** is necessary to eliminate locations where the methane can form.
- Cementite and the carbon activity should **be minimized or eliminated** to avoid methane formation.
- The **cost** factor should be considered to produce a cheaper yet more resistant steel to HTHA.
- Figure 3 shows the effect of chromium on the the cementite content.

Heat treatment

- API 941 **lacks** information about the heat treatment of steels to resist HTHA.
- Such a factor plays a huge role by **defining the microstructure, lowering carbon activity and ensuring the precipitation of only stable carbide at grain boundaries**, where HTHA usually occurs.

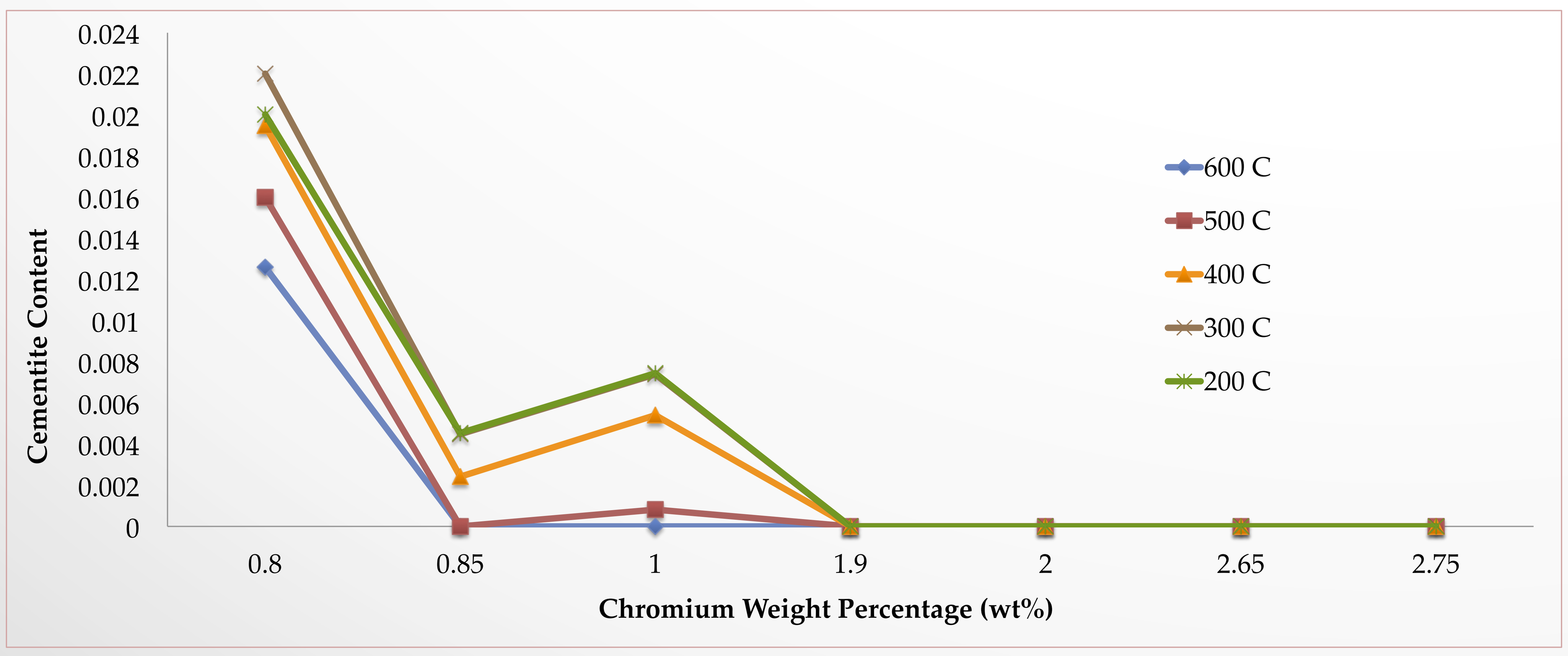

Figure 3: Chromium Effect on Cementite Content at different temperatures.

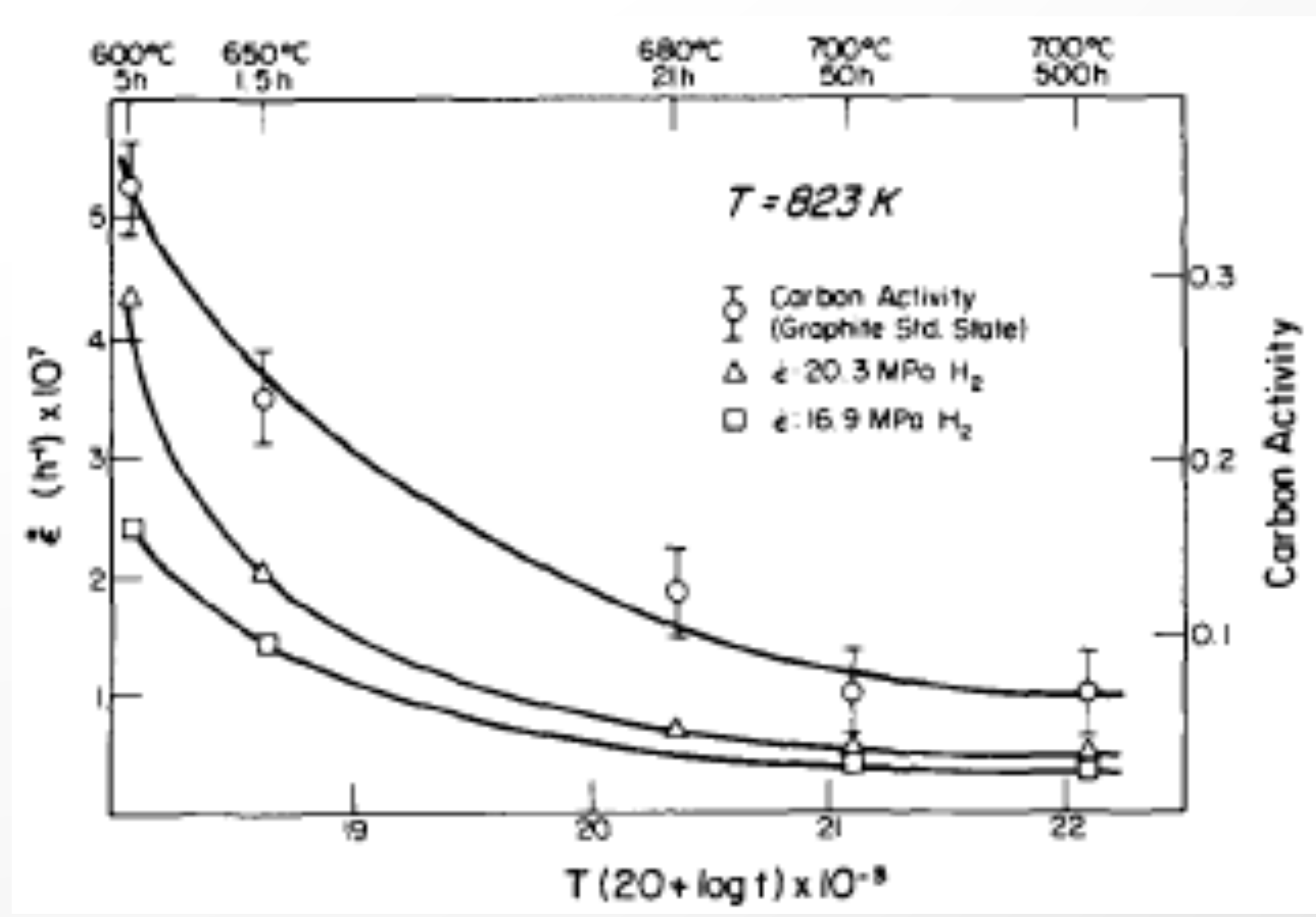

Figure 4: Variation of Carbon activity and HA strain rates with the tempering parameter.

References:
- *American Petroleum Institute Publication*, Vol 941, 8th Edition (2016).
- Moro, L. *et. al.* (2007), *"Influence of Chromium and Vanadium in The Mechanical Resistance of Steels"* Materials Chemistry and Physics, V: 109, P: 212-216.
- Parathasarathy, T.A. and Shewmon, P.G. (1984), *"Effects of Tempering on the Carbon Activity and Hydrogen Attack Kinetics of 2.25 Cr-1 Mo Steel"* Metallurgical Transactions A, V: 15A, P: 2021-2027.