Hydrogen in steel

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Hydrogen (H) (atomic number 1， atomic weight 1.008) is a colorless gas. It has a density of 0.0899 g/l. The melting point of hydrogen is -259.2 degrees C and the boiling point is -252.8 degrees C. The phase diagram of fee-hydrogen is shown in Figure 1.

Figure 1 Fe-H phase diagram

H in steel is considered to be an undesirable impurity and quite harmful in some applications. It has always been a source of various problems in steel production due to its general detrimental effect on the processing characteristics and serviceability of steel products. Just a few parts per million of H dissolved in steel is enough to cause harm. Therefore， it should be avoided or removed as required when necessary.

Sources of hydrogen

Hydrogen has several sources and can enter the steel in several ways. In primary steelmaking furnaces， the source of hydrogen is water， which enters the furnace through wet scrap， molten material， ferroalloys and refractory materials that are not completely dry. The water dissociates on contact with the steel， producing H， which is absorbed by the steel. This H is usually removed by the purging action of carbon (C) boiling， but some remains in the steel.

Contact of the steel with moisture and/or moist air in the ladle refractory can result in the absorption of H by the steel.

Hydrophilic calcium oxide (CaO) in the slag and decomposition of the refractory (which requires sufficient resistance to thermal shock) can also cause H to enter the steel.

The dissociation of the water vapor contained in the furnace gas produced during steelmaking using hydrocarbon fuel combustion (equation below) produces H that can be absorbed by the steel.

$H_2O (g) = 2[H](g) + [O](g)$

However， at any point in steelmaking， the H content of the steel is determined by the balance between the entry of H from the gas into the steel and the competing reactions of H removal by carbon boiling and degassing.

At low levels of carbon， the rate of H uptake is higher than its rate of removal. The dissolved H content in the steel melt drops to a minimum level at the end of carbon boiling， but it increases again with the addition of ferroalloys and synthetic slag.

The H content of liquid steel is lower when steel is made in a high frequency induction furnace compared to the practice of electric arc furnace steelmaking. Also， the hydrogen content of steel produced under oxidizing acid slag is lower than that produced under reducing slag.

Steel in the solid state can also absorb hydrogen by the action of electrochemical reactions that occur on the steel surface. The most common examples of this phenomenon are pickling， electroplating， cathodic protection and corrosion. The H released during the electrochemical reaction is partially absorbed by the surface of the steel before recombining into harmless hydrogen bubbles. The presence of sulfides， arsenides， phosphides and selenides in the electrolyte contributes to the absorption of H in steel because these compounds inhibit the recombination reaction of H.

H can also enter steel when it is exposed to gases at high temperatures and pressures. This is a fairly common phenomenon for H absorption in chemical and petrochemical processing equipment. Water vapor and hydrocarbons are also harmful in this respect.

Usually， H dissolves in the interstitial spaces of steel in the form of single atoms， but it is not known whether it dissolves as atoms or protons.

Solubility of hydrogen in steel

The units used to express the H content in steel are parts per million (ppm) and milliliters or cubic centimeters of H per 100 grams of steel corrected for standard temperature and pressure. the relationship between these two units is: 1 ppm = 1.11 ml/100 gm.

The solubility of H in steel depends to a large extent on the crystal structure， temperature and composition. h is much more soluble in austenite (iron) than in ferrite (Fe and Fe).

Diatomic H gas reacts with steel and dissolves into it in atomic form according to Sievert's law.The data on the solubility of H are summarized by the following equation and shown in Figure 2

H_2 (g) =2 [H] (dissolved in steel)

The following equation represents the equilibrium constant in the above reaction.

K = [ppm H]/ (pH_2)?

For α， δ (bcc) iron， γ (fcc) iron and liquid iron (liquid)， the temperature dependence of K at equilibrium at pH_2 = 1 atm is given by the following equation

Log K(α， δ) = -1418/T+ 1.628

Log K (gamma) = -1182/T+ 1.628