

# Significance of Hydrogen Control in the Welding of Low Alloy Steels

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## SYNOPSIS

*As a joining operation, welding plays by far the most important role in the fabrication industry. To keep the rejection rates low, quality of welding has to be of the highest order. The present paper deals with the role of hydrogen in the welding of low alloy steels.*

### 1. HYDROGEN IN WELDS

In the welding of low alloy steels, particularly high tensile class, cold cracking has been a serious phenomenon and needs to be prevented at all costs. As cold cracking is influenced by hydrogen content to a considerable extent, control of this element becomes an important consideration for the welding technologist.

#### 1.1 Sources of Hydrogen in Weldments

Hydrogen can be derived from a number of sources such as parent metal, consumables, coatings/fluxes and welding atmosphere.

##### *Parent Metal*

The following factors introduce hydrogen in parent metal :

- (i) Product of combustion in the furnace atmosphere in steel making.
- (ii) Metallic charge—scrap, pig iron etc.
- (iii) Nonmetallic charge—lime stone, ore etc.
- (iv) Deoxidisers and other alloying elements.

- (v) Slag cover and water vapour in the furnace atmosphere.

The concentration of hydrogen in pig-iron varies from 3.5ml/100gm. to 10ml/100gm. (See Table-1).

The hydrogen content of steel scraps depends largely on its form and condition. Light, rusty scrap contains higher hydrogen than clean solid scraps.

TABLE 1

Material	Hydrogen (ml/100gm)
Assorted C	35-42
Ni-Cr billet Crops	50
Pig-iron Solid	3.5-10
Nickel shot	85-93
80% ferromanganese	18-133
70% Silico-Manganese	73-80
Spiegel (2.28% Si, 8.45% Mn)	47-60
Ferrosilicon	2-4.2
70% Ferrochrome	2-21
70% Ferromolybdenum	3-11
Ferro-Titanium (40%)	36
Ferro Vanadium (50%)	20
Carbon Steel	4.6
4% Cr Steel	5.5
18/8 Stainless Steel	10.3

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*Welding Consumables*

- (a) In manual metal arc welding which is the most versatile process, most of the hydrogen comes from the coating of the electrodes. High cellulose electrodes generally give around 20-30ml/100gm. Rutile based coatings generally give rise to hydrogen around 12-15ml/100gm and sometimes up to 20ml/100gm. In basic coatings, total hydrogen content does not usually exceed 10ml/100gm.
- (b) Hydrogen sources in SAW are as follows:
  - (i) Potential hydrogen in flux.
  - (ii) Water vapour pressure in welding atmosphere.
  - (iii) Hydrogen in the wire and on the surface.

Hydrogen from the above sources enters into the arc cavity. Hydrogen goes to the molten pool and a part escapes away from the cavity. Contribution of hydrogen from wire and base metal is comparatively small. (Table 2).

**TABLE 2**

**Hydrogen content of the wire and the test piece**

Position	hydrogen contents (p.p.m)	detail of sampling position
a	2.8	
b	2.0	
c	1.3	
d	1.0	
e	0.9	
f	0.9	
g	0.9	
h	0.6	
base metal	0.1	-----

Chemical Composition of wire: C-0.12, Mn-1.96, Si-0.02, P-0.012, S-0.009.

In SAW, the effect of water vapour pressure in welding atmosphere is comparatively small than in SMAW.

Table-3 gives diffusible hydrogen and residual hydrogen in weldmetals, dissolved hydrogen in slag and potential hydrogen in fluxes for submerged arc welds. This indicates contribution from different sources.

Fig. 1. shows the relation between total hydrogen in weld metal and square root of potential hydrogen in flux and is given by the relation

$$[H]_T = 3.69 \sqrt{[H]_F} - 4.35 \quad (1)$$

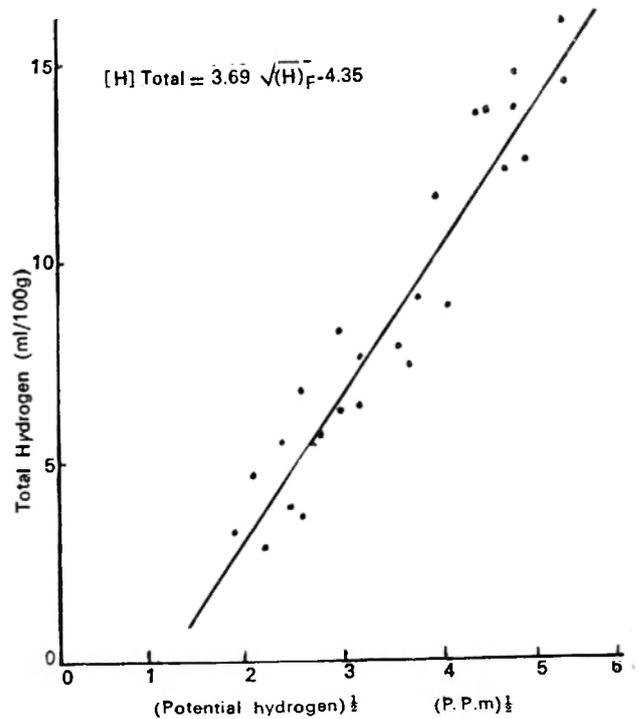


Fig 1. Relation between square root of potential hydrogen and total hydrogen.

- (c) In electroslag welding, the sources of hydrogen are as follows :
  - (i) Flux moisture content
  - (ii) Atmospheric humidity
  - (iii) Flux basicity
  - (iv) Slag cap height
  - (v) Electrical input parameters
  - (vi) Wet asbestos when used
  - (vii) Gap width

TABLE 3

Flux Nos.	Diffusible hydrogen (ml/100gm.)	Residual hydrogen (ml/100gm)	Total hydrogen (ml/100gm.)	Hydrogen in slags (ppm)	Potential hydrogen (ppm)
CS 1	2.2	0.7	2.9	1.4	4.8
2	4.7	0.8	5.5	2.0	5.9
3	11.4	2.3	13.7	3.3	19.0
4	7.9	1.0	8.9	3.0	16.5
5	10.5	1.1	11.6	4.9	16.4

By using D C (—), hydrogen pick-up in the weld increases slightly.  $(OH)^-$  ion is found to be more responsible for the weld metal hydrogen pick-up. Nakano's study found that increase in basicity of the flux from 0.42 to 1.33 increases the hydrogen level from 3ml/100gm. to 8ml/100gm. The increase in gap width also increases the hydrogen content in weld metal due to the increase in reaction area which allows more of the available hydrogen to enter into the weld metal.

- (d) Gaseous shield in case of MIG and TIG welding generally gives much lower levels of dissolved hydrogen (<5 ppm) in the weld metal.

## 2. EFFECT OF HYDROGEN ON CRACKING TENDENCY AND WELD PROPERTIES

As already stated, the amount of hydrogen introduced into the weld metal depends upon the nature of coating/fluxes and free moisture content in the surroundings etc. Hydrogen diffuses into the underbead region and the area in the vicinity of the weld and slowly accumulates to above equilibrium content for the steel which is less than 1ml/100gm for alpha iron (Fig. 2). When the weld cools down, the hydrogen supersaturation gives rise to concentration of hydrogen at discontinuities such as grain boundaries, inclusions etc. Here, the atomic hydrogen recombines to form molecules of insoluble hydrogen gas, setting up very high local pressures and stresses. The sum of stresses set up by this conversion to molecular hydrogen on the

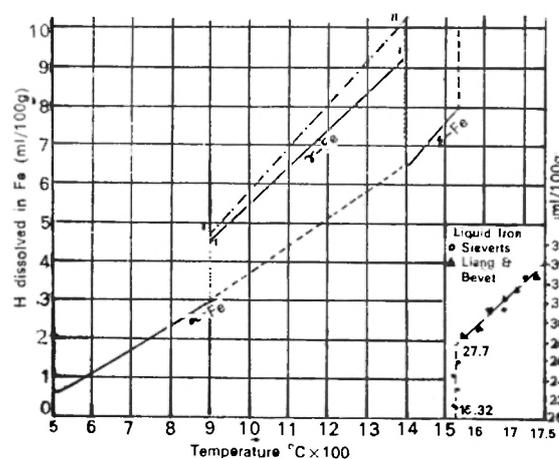


Fig 2. Variation of the solubility of hydrogen in iron in the solid and liquid states.

one hand and thermal contractions and possible transformations in the steel on the other, may lead to a total stress in excess of the breaking load for the material, resulting in cracking. Pressure developed at room temperature by the transformation of hydrogen from atomic to molecular state is over 100000 atms per mole.

The hydrogen evolved as above tries to diffuse out of the steel. Sykes *et. al.* computed the diffusivity values of hydrogen in alpha iron at different temperatures from permeability data. Hill and co-workers proposed the following relationship for diffusion above 200°C.

$$D \text{ cm}^2/\text{sec} = 1.4 \times 10^{-3} \exp (-3200/RT)$$

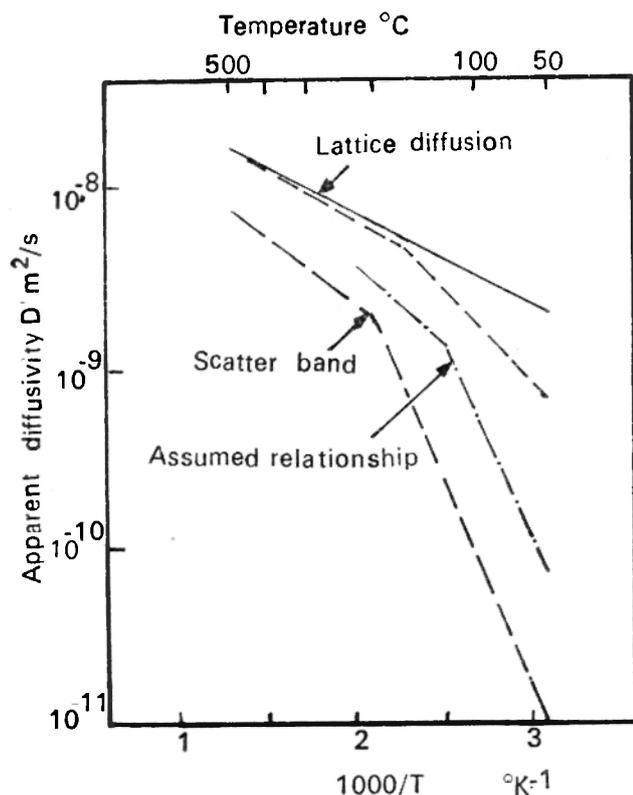


Fig 3. Apparent diffusivity for hydrogen in iron and steels according to Andersson.

Another relation given by Andersson is given in fig. 3. and equation below :

$$D \text{ cm}^2/\text{sec} = 0.12 \exp(-7820/RT)$$

As seen from the figure 3, diffusivity drops sharply below 200°C.

Residual hydrogen in the welds after diffusion leads to cracking by the above mechanism, when the quantity of  $H_2$  is high and a susceptible microstructure is present.

It is generally recognised that root cracking in welds of low alloy steels initiates during cooling at the HAZ at temperature below 90°C.

Hydrogen diffusion and evolution from a weld metal is quite active at temperature above 150°C or thereabout. Satoh and his co-workers found that local hydrogen accumulation starts about 20 seconds after welding at temperature of about 150°C and reaches its maximum in one to two hours. Delayed cracking phenomenon is the result of slow accumulation of residual hydrogen at the crack initiation points.

### 3. CONTROL OF HYDROGEN

From the above discussions, it is very clear that  $H_2$  content of the welds needs to be controlled for obtaining a crack free satisfactory weld. The methods adopted for this are :

- (i) Enhancing the diffusivity of hydrogen by maintaining higher preheat and interpass temperature
- (ii) Control of hydrogen content of consumables
- (iii) Imparting a suitable microstructure to the HAZ and weld metal to make them more resistant to hydrogen induced cracking

#### 3.1 Controlling cracking tendency by improving diffusivity of hydrogen

In the weld joints, diffuses into two main directions : length and width.

The following general equation is valid for two dimensional diffusion :

$$\frac{\partial c}{\partial t} = D(T) \left[ \frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right]$$

Where  $c$  = Concentration  
 $t$  = time  
 $T$  = Temperature  
 $x, y$  = Spatial co-ordinates.

The hydrogen diffusion out of industrial butt welds can be estimated by the following equation as per Andersson :

$$(C_{av}/C_o)_{2D} = [\bar{\phi}(t, w)]^2$$

Where  $C_{av}$  = Average concentration of  $H_2$  at time  $t$   
 $C_o$  = Initial concentration of  $H_2$   
 $t$  = time  
 $w$  = Plate thickness

To bring down the hydrogen level to a minimum value by diffusion, a suitable soaking time and temperature is needed. Figs. 4 to 6 show the calculated soaking times for three different temperatures for the removal of 50%, 75%, and 90% amount of initially dissolved hydrogen, at soaking temperature of 50, 100, and 200°C. From the above diagrams, it is possible to get an estimate of soaking time for butt welds (single V). The

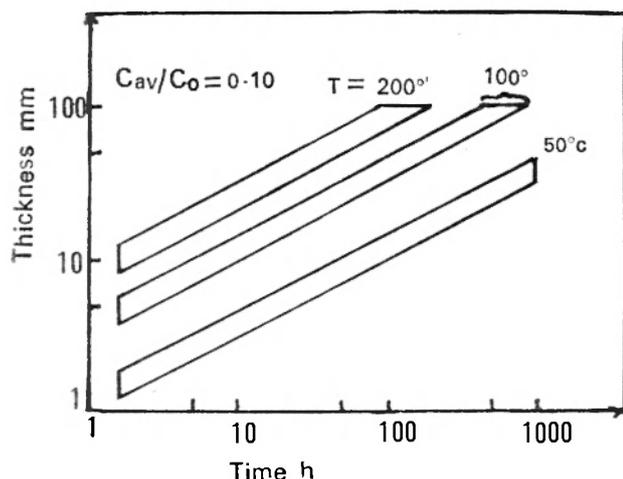


Fig 4. Soaking time for  $C_{av}/C_o=0.10$

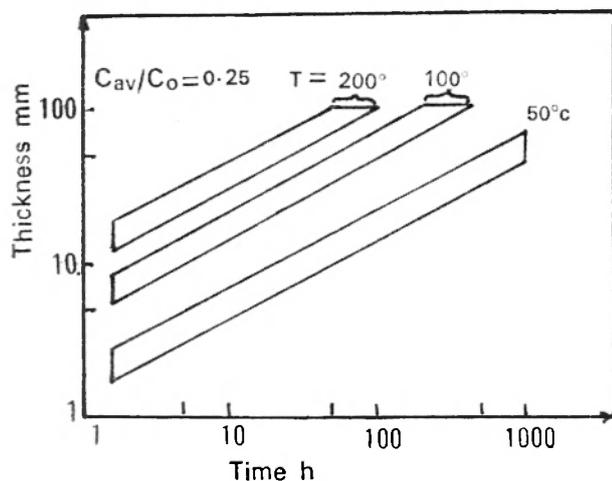


Fig 5. Soaking time for  $C_{av}/C_o=0.25$

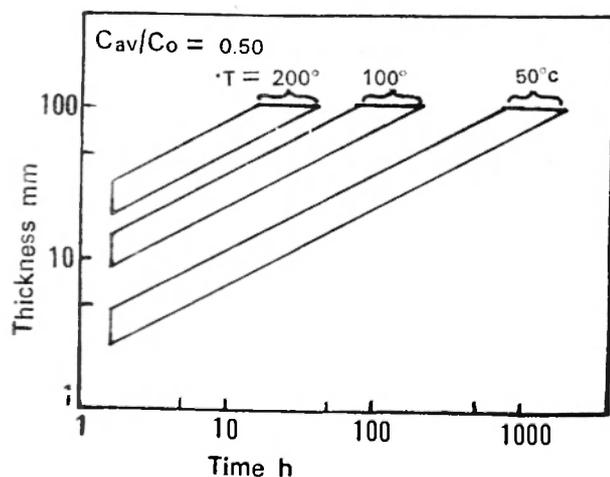


Fig 6. Soaking time for  $C_{av}/C_o=0.50$

diagrams also show that by increasing the temperatures slightly, the time can be reduced drastically because of very much increased diffusion.

### 3.2 Control of Hydrogen in consumables and parent metal

Some researchers have indicated that if  $H_2$  content is controlled within 0.5ml/100gm to 1ml/100gm, preheating temperatures can be brought down drastically. Hydrogen content of electrodes is severely affected by the nature and basicity of the coating. It is also severely affected by the welding atmosphere (relative humidity) besides the coating. It has also been found that the rust or wet scale on the groove surface or primer used for painting of the jobs, increases the hydrogen content in the weld metal by as much as 2ml/100gm.

Effect of exposure conditions of the electrodes on the hydrogen pick-up is given in Table-4. The data is given for low hydrogen electrodes which were baked at 350°C for 1 hr. and then subjected to various exposure conditions indicated in Table. In the same way, as in consumables, preheating of parent metal removes hydrogen depending on time and temperature.

TABLE 4

#### Effect of Exposure conditions on Pick-up of $H_2$

Type of Electrode	Exposure conditions at 35°C		Hydrogen ml/100gm.
	% RH	Hours of exposure	
E 7018 (Baked 350°C/ 1hr. before exposure)	As baked	—	5.8
	70	1	6.75
	70	2	4.64
	70	10	6.96
	80	1	6.77
	80	5	10.27
	80	10	6.24
	80	20	12.91

Note :— $H_2$  content determined by Mercury method.

3.3 A tough microstructure is very important in tolerating higher amount of  $H_2$ . Fig. 7 shows that baking increases capability of the material to sustain higher applied stress. This is related to the

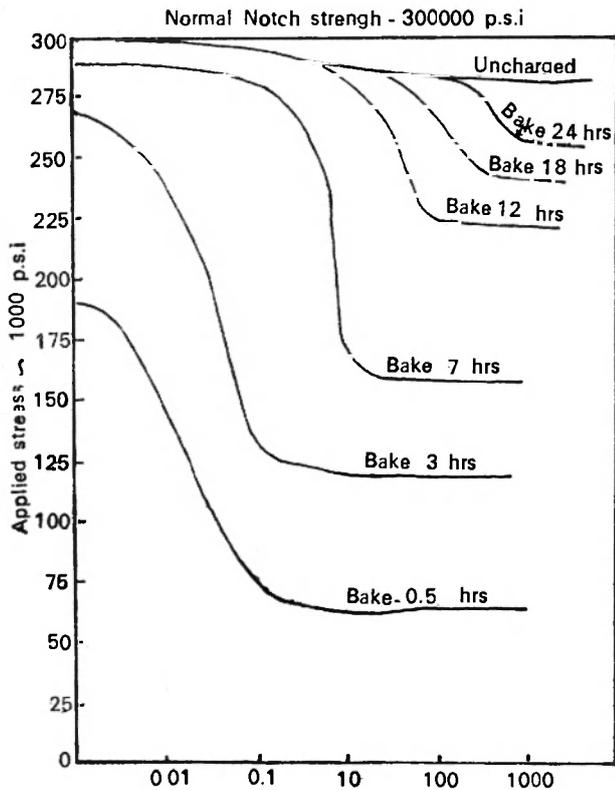


Fig 7. Fracture time hours

microstructure as well as the stresses generated due to hydrogen. By giving preheat and subsequent post heating, microstructures of weld metal as well as HAZ get modified. A tough microstructure is more resistant to hydrogen induced cracking than a brittle one.

3.4 Hydrogen specification in welding consumables

H<sub>2</sub> tolerance of various steels vary widely depending on composition, strength and structure. Values of diffusible hydrogen contents (glycerine displacement procedure) specified for low hydrogen electrodes for higher tensile steels, are given by Suzuki and co-workers as below :

Tensile Strength Kg/mm <sup>2</sup>	H <sub>2</sub> (ml/100gm) maxm.
50	8 or less
55	6 or less
60	4 or less
70-100	3 or less

As the strength increases, lower H<sub>2</sub> values are demanded from the welding electrodes. This is besides the preheating specified for the joints.

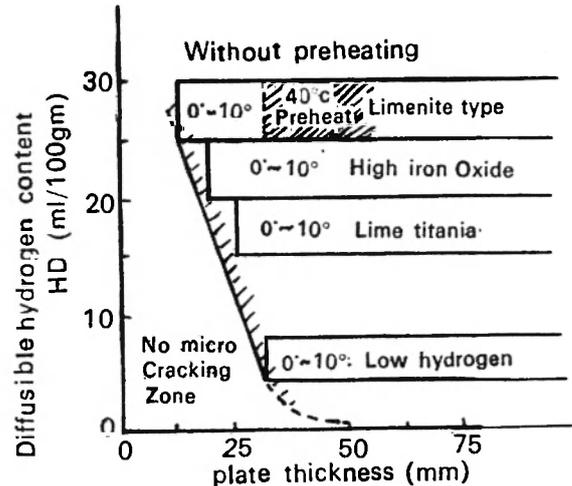


Fig 8. Range of plate thickness and diffusible hydrogen content to induce micro-cracking in mild steel manual welds made at 0 to 10°C.

With low hydrogen electrodes (<10ml/100gm), HT 50 steel plates thinner than 32mm were found free of microcracking by Yurioka even when welded at room temperature (Fig. 8). Yurioka & his co-workers have proposed the following formula for critical preheating temperature to avoid micro-cracking :

$$T_0 \text{ (}^\circ\text{C)} = 120 + 120 \log \left( \frac{H_D}{3.5} \right) + 5.0 (h\omega - 20) + 8 \times (\sigma_B - 83)$$

Where H<sub>D</sub> = Diffusible hydrogen content of deposited weld metal (0.1 to 40ml/100gm.)

σ<sub>B</sub> = Tensile strength of weld metal (60 to 90 Kg/mm<sup>2</sup>)

hω = Weld metal thickness (15 to 40mm)

4. DISCUSSIONS

From the earlier discussions it is evident that increasing diffusivity by high preheat temperature and lowering hydrogen potential in welding consumables would help substantially in controlling hydrogen induced cracking. While control of hydrogen to a very low value would decrease the cracking tendency drastically, control of preheat and post-heat has been one of the solutions due to techno-economic reasons.

Filler metals need to be designed with proper ingredients to prevent hydrogen input in welds. Drying of the consumables plays an important role in this. By control of only the preheat, very high preheat temperatures are needed for thicker sections and it creates a lot of problems in fabrication including loss of productivity. To circumvent this, technological ways of control of welding methods including special manipulation techniques with control of hydrogen in consumables have been taken recourse to.

In welding such materials, the welding passes are so ingeniously laid that next pass is deposited immediately after and over the first pass, the next hot pass serving the purpose of preheating and thus promoting diffusion of Hydrogen in the weld and HAZ.

Cracking tendency can be reduced considerably by this technique. As per Suzuki and Yurioka, preheating of HT 50 steel plates can be lowered by as much as 75°C by giving a hot pass immediately. Excessive lowering of preheating temperature however is not desirable as otherwise micro-cracks may develop.

Preheating in the welding of structural steels can also be reduced if not eliminated by additional care and extra supervision as mentioned below :—

- (i) Larger weld run size may be used provided the distortion is not a problem.
- (ii) Multiple electrodes or welders may be simultaneously employed to supply heat to the joint.

Two welders following each other very closely or working from either side of the joint will increase the heat input.

- (iii) When the joint is small, and more than one welder cannot work there, heat input can be raised by making the first run and putting second run right over it, after deslagging in the hot condition.

By control of hydrogen potential of consumables, preheating temperature can also be very much reduced as shown in Fig. 8. Less preheating also means :

- (i) Less heat input and less distortion.
- (ii) Less expenses on preheating (fuel saving)
- (iii) Less loss of useful working hours (higher preheat needs more time to reach the specified temperature)

- (iv) With higher preheating temperature, the productivity also goes down as the welder cannot work for longer time, thus less arc time.

## CONCLUSIONS

- (1) Consumables used for welding and welding atmospheres are the main source of hydrogen going into the weld metal.
- (2) Hydrogen content of an electrode is seriously affected by the atmospheric humidity where test welding is done.
- (3) By controlling the diffusible hydrogen content of welding consumables, preheat temperatures can be significantly brought down.
- (4) Hydrogen induced cracking can also be controlled by improving the diffusivity of Hydrogen.
- (5) Technological means such as laying down immediate hot pass can improve the diffusivity of hydrogen and reduce the degree of preheat.

## ACKNOWLEDGEMENT

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