MEASUREMENT OF DIFFUSIBLE HYDROGEN IN STEEL WELDMENTS - A STATUS REPORT

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ABSTRACT

Hydrogen Assisted Cracking (HAC) is the most widely encountered cracking problem in the welding of ferritic steels. One of the methods to mitigate this type of cracking is to control and minimize the amount of diffusible hydrogen content in the welds. This, in turn, calls for standard test methods to measure diffusible hydrogen present in weldments made with different welding consumables, processes etc. This report describes test methods to measure diffusible hydrogen in the welds as per different International Standards. It also highlights the deficiencies in the present Indian Standard for measurement of diffusible hydrogen and suggests revision of the standard to cover Submerged Arc Welding, Gas Metal Arc Welding and Flux Cored Arc Welding Processes in addition to Manual Metal Arc Welding Process. It also recommends inclusion of Gas Chromatography Method and removal of glycerin method in the Bureau of Indian Standard (BIS) specifications.

INTRODUCTION

One of the main problems associated with the welding of ferritic steels is that of hydrogen assisted cracking, popularly known as cold cracking or delayed cracking. As the name suggests, it is caused by the hydrogen present in the weld metal. In addition to hydrogen, a microstructure susceptible to cracking and presence of restraint stress are also necessary for cracking to take place. Hydrogen enters the weld pool from welding arc during welding. The main source of hydrogen is the moisture present in the flux coating of the welding electrodes in the case of Shielded Metal Arc Welding (SMAW) or flux used in the Submerged Arc Welding (SAW). Other sources of hydrogen include moisture present as impurity in the shielding gases used for Gas Metal Arc (GMA) and Gas Tungsten Arc (GTA) welding, corrosion products and other impurities like grease that may be present at the uncleaned base metal surface.

Solubility of hydrogen shows a wide variation with temperature and microstructure. A typical variation of solubility of hydrogen in pure iron is given in **Fig. 1**[1]. It can be seen that the solubility is much lower in the ferrite phase than in the liquid or the austenite phases. Hence, as the weld metal solidifies and later transforms into ferrite, the hydrogen dissolved in the liquid metal become supersaturated in the ferrite. Not all this hydrogen can diffuse out from the weld during cooling. This results in a weld metal supersaturated with hydrogen at the end of the welding cycle. As the diffusion coefficient of hydrogen is sufficiently high even at room temperature, hydrogen diffuses into the adjacent heat affected zone of the weld and a part of it also escapes to atmosphere. During this process some of the hydrogen atoms

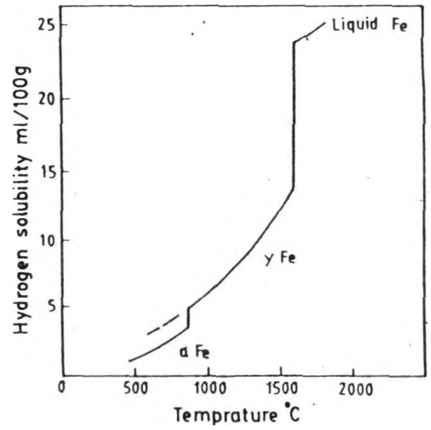
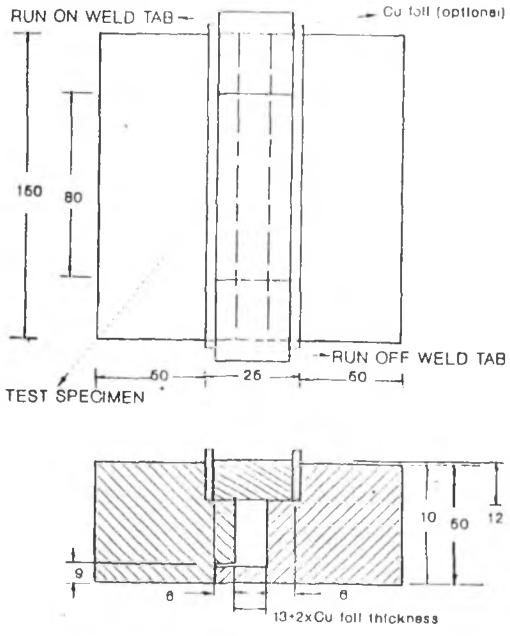


Fig. 1 : Solubility of hydrogen in pure iron as a function of temperature [1]

combine and form hydrogen molecules which get trapped at the various defects like micropores, inclusions etc. The hydrogen thus trapped is called residual hydrogen and does not contribute to hydrogen assisted cracking. The atomic hydrogen which slowly diffuses through the weld and HAZ is called the diffusible hydrogen. It is this hydrogen which causes hydrogen assisted cracking. Therefore, it is necessary to quantify the amount of diffusible hydrogen (H_D) in order to study the susceptibility of weldment to HAC. As the main source of hydrogen is the flux coating in the welding consumables, the unit used to represent the value of H_D is ml/100gm of weld metal. Sometimes ml/100gm of fused metal is also used. In this report, various methods available for measurement of diffusible hydrogen are received and a comparison of different standard methods is made.



(All dimensions are in mm)

Fig. 2 : Weld Test Assembly along with Copper Fixture as per AWS Specifications [2]

Measurement of H_D essentially consists of a) preparation of weld test assembly, and b) measurement of hydrogen. Methods recommended for preparation of weld and measurement of hydrogen by different standards are described in detail below.

PREPARATION OF WELD TEST ASSEMBLY

Specimen for Hydrogen Measurement

The specimen for the preparation of the weld pad consists of three parts; a run-on tab, a run-off tab and a center piece. The material for all the three pieces of the test assembly should be non-rimming quality steel of grade ASTM A36 or SAE 1020. Only the center piece is used for measurement. Different standards specify different dimensions for the specimen. According to AWS A 4.3-86, [2] all the three pieces should have a cross section of 25 x 12 mm ± 2mm and the center pieice of length 80 mm ± 5 mm. **Fig. 2** shows the weld test assembly in a copper clamping fixture. ISO 3690 [3] recommends the use of test pieces of cross section 10 x 15 mm. The length of the center piece is 30mm and that of run-on and run-off tab is 44 mm each. It allows a tolerance of ± 0.25 mm only. However, for multiple measurement it allows the use of center piece consisting of four separate pieces of length 7.5 mm each as shown in **Fig. 3** or three pieces of each one is 15 mm and two pieces are 7.5 mm length each. The material should be non-rimming quality steel conforming to ISO/R 630 Fe 37B or its equivalent. Preparation of test assembly for SMAW process in IIW method [4] is very much similar to that of ISO standard.

BIS specifications for H_D measurement is given in IS : 11802-86[6]. It also recommends same copper jig as that specified by ISO standard and a three piece test assembly made of structural steel conforming to IS:2062. Dimensions of the test piece assembly are also same as that prescribed by the ISO standard.

All the standards recommend degassing of the specimen by heating before welding. It is generally carried out at 650°C for 2hr. (1hr. as per BIS) either in vacuum or in an inert atmosphere.

Welding Procedure

As per AWS standard, if the measurement is carried out for classification of electrodes, fluxes and gases based on diffusible hydrogen content of the deposited metal, the welding conditions shall duplicate those used for preparing the weld test assembly for fabrication of tensile test specimen required by the applicable AWS filler metal specifications. However, standard permits the use of stringer bead technique only even if weaving is used for preparing weld test specimen for mechanical testing. For making the test bead, the arc is initiated on the starting weld tab at a point such that the leading edge of the deposit shall be 25±6 mm from the leading edge of the test specimen. Welding is carried out in an uninterrupted manner along the weld test assembly to the run-off weld test tab and is terminated on it at a position such that the trailing edge of the crater is on the run-off tab within 25 mm of the trailing edge of the test specimen. This makes the total length of the weld around 130 mm. For SAW process, the standard specifies that flux once used for welding should not be reused.

ISO standard, DIN standard and IIW method specify similar conditions for making the weld. The temperature of the jig should not be more than 5°C than the ambient. The welding is carried out using 15 A (10 A for DIN standard) less than the maximum current specified for the electrode and is controlled within an accuracy of ±5 A. The speed is adjusted to an electrode consumption of 1.2 to 1.3 cm for one cm of the weld deposit. Unlike AWS standard, these standards do not give any guidelines regarding the start or end position of the weld in the run-off tabs respectively. In addition to this, DIN standard specifies separate drying conditions for basic and non-basic electrodes. Similarly, IIW method recommends that for classification of covered electrodes, procedure given in ISO 2560 - Covered Electrodes for Manual Arc Welding of Mild Steel and Low Alloyed Steel - Codes for Symbols and Identification, shall be followed.

BIS recommends the use of 4 mm electrode except for iron powder electrodes with over 130% metal recovery for which 3.15 mm electrode is recommended. Electrodes should be dried as per the recommendations of the manufacturer. In the absence of such recommendations it prescribes separate procedures for drying low hydrogen, cellulose and other electrodes. Welding procedures are the same as those recommended in the ISO standard. The IIW method describes the welding procedure to be adopted for SAW and GMAW processes in addition to that for SMAW. For SAW it recommends the use of welding fixture shown in **Fig. 4** for preparation of the specimen. The dimensions of the center piece are the same as those for SMAW process, but it may be aligned suitably as shown in **Fig. 5**. The run on and run-off pieces are of dimensions 30 x 10 (or 15) x 135 mm. and the total length of the weld bead should be 260 mm. The flux used for welding is dried as per manufacturer's instruction in an open dish placed in a drying oven. If there are no drying instructions, drying shall be carried out at 350°C for 2 hr. Used flux is not recommended for reuse. Flux is kept at predetermined constant depth of 30 mm by leveling off along the top of the copper foil insert. For the preparation of test assembly, as per this standard, welding is carried out at a welding current of 625±25A, voltage of 30±1V, speed of 10±1mm/s and stick out of 30±5mm. Further

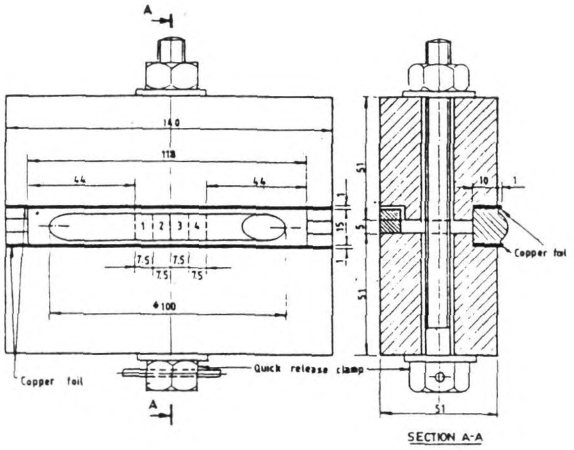


Fig. 3 : Weld Test Assembly along with Copper Fixture as per ISO Specifications [3]

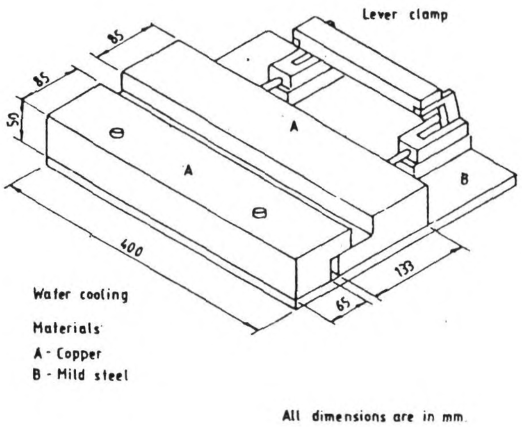


Fig. 4 : Fixture for Preparation of Diffusible Hydrogen Welding Specimen for Submerged Arc Welding as per IIW Method [4]

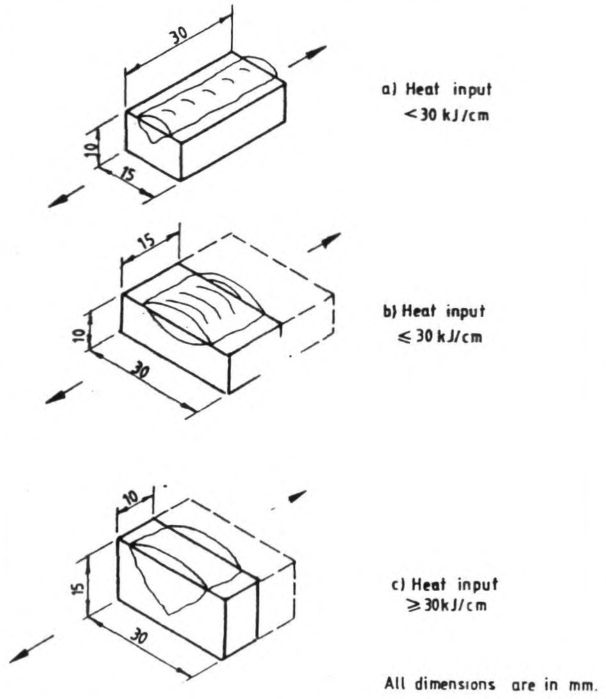
processing of test specimens after welding is carried out as described for manual metal arc welding.

For GMAW welding, test assembly as shown in Fig. 3 is used. If weld bead cross section is compatible with a 15 mm test piece assembly, the center piece is aligned as shown in **Fig. 5(a)**. For large weld bead, center piece alignment, as shown in **Fig. 5(b)**, is used and in this case the cross section of run-on and run-off pieces should be 10 x 30 mm with a length of 45 mm. Welding conditions are chosen by trial so as to produce a weld bead which is normal for the diameter of the electrode and heat input used. Other procedures recommended are similar to those recommended for SMAW.

DIN standard also gives welding procedures for SAW separately in DIN 8572 part 2 [7]. It distinguishes tow separate case of diffusible hydrogen, one due to a specific wire-flux combination and the other due to contribution of flux alone. In order to measure diffusible hydrogen contributed by flux alone, it recommends the use of wire conforming to DIN 8557 - S3 vacuum, degassed at 650°C. The copper jig specified in this standard is similar to that recommended for SMAW in DIN 8572 part 1, but of slightly larger dimensions. The total dimension of the three test piece assembly is 200x25x15 mm as against 130x15x10 mm in the case of SMAW. Each of the four specimens in the center piece is of length 10mm and the total length of the weld bead is about 190 mm. Drying conditions for the flux are similar to those of the IIW method. Recommended welding parameters are current = 580±20A, voltage = 29±1V and welding speed = 55±3cm/min. Further processing of the prepared specimen is similar to that recommended for SMAW.

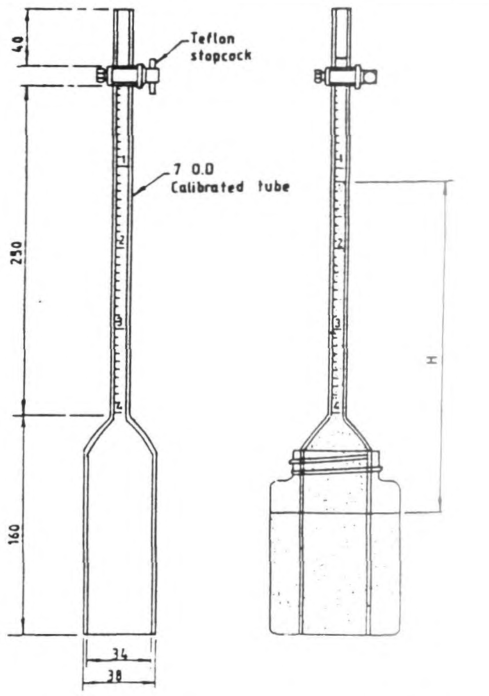
Cleaning and Storage

Soon after welding, the test assembly is removed from the copper fixture and plunged into ice water and stirred vigorously. Later it is transferred to a low temperature liquid bath (<-60°C) for storage, if measurement of hydrogen cannot be carried out immediately. A mixture of acetone and solid carbon dioxide or liquid nitrogen can be used for storage. For durations longer than three days, liquid nitrogen is recommended. Before analysis, the test assembly is further processed to remove the slag coating and to separate the run-on and run-off tabs from the center piece. For this, the test assembly is removed from the low temperature liquid bath. However, the maximum time spent outside the bath for each operation should not exceed one minute as per



Alternative alignment of specimens in the welding

Fig. 5 : Alternative Alignments of Specimens with Increasing Heat Input in the Fixture as per IIW Method[4]



ALL DIMENSIONS ARE IN mm

Fig. 6 : Schematic of diffusible Hydrogen Measurement Set Up as per Aws Specification [2]

AWS standard and 10 s. as per ISO standard. After this time, the test assembly is immersed back into the liquid bath for a minimum of 2 minuted and taken out for further processing till the cleaning process is complete. During the processing, the temperature of the test assembly should not exceed 0°C. The run-on and run-off tabs may be broken by cooling the test assembly to liquid nitrogen temperature and hammering on one end. ISO, BIS and DIN standards also specify that just before taking the specimen for hydrogen measurement, it should be washed first with ethanol, then with either and finally blown dry with a stream of dry nitrogen. These operations shall be completed within 20-22s.

MEASUREMENT OF DIFFUSIBLE HYDROGEN

Measurement of diffusible hydrogen is carried out using the specimen prepared as described above. The most widely used method is the collection of hydrogen evolved from the specimen over a liquid column using a eudiometer. Different liquids like glycerin, mercury, silicone oil etc. are used for this purpose [8]. Among these, only mercury is recommended in most of the standards as repeatable results are obtained only when this liquid is used for measurement. Other liquids dissolve some of the hydrogen evolved from the samples and hence are less reliable. Glycerin is the next most widely used liquid and some standards accept Glycerin method as a standard method for measuring diffusible hydrogen [6,9,10] Another method of measurement which has been included in many standards is the collection of the gas in a chamber and its measurement by Gas Chromatography [2,11]. These three methods are described in detail below.

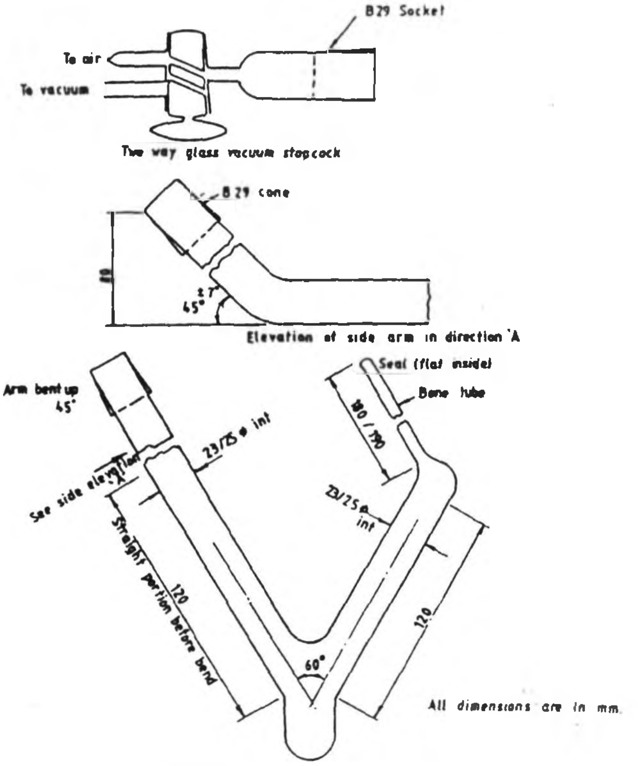


Fig. 7 : Schematic of Diffusible Hydrogen Measurement Set Up as per IIW Method [4]

Mercury Method

There are some major differences in the apparatus recommended for measuring diffusible hydrogen in AWS, ISO and BIS though the basic principle is the same. AWS standard uses a simple equipment for measuring diffusible hydrogen by mercury method. It essentially consists of a plastic vessel containing mercury and a eudiometer provided with a stop cock as shown in **Fig. 6** and connected to a vacuum system. Prior to the test, the plastic jar containing mercury is kept in a bath maintained at 45°C. Sample is introduced into the eudiometer tube and held vertical by means of a magnet and the tube along with the specimen is slid into mercury. By using the vacuum pump, mercury is drawn up into the eudiometer around the sample. Stop-cock is closed while the mercury is drawn to half way up the mark in the calibrated portion of the eudiometer. Sample and the tube are bounced slightly against the bottom of the jar to remove any entrapped air bubbles. After this, stop-cock is again opened and the mercury is allowed to fill the tube completely and just above the stop-cock opening. Stop-cock is then closed and vacuum line is removed. Hydrogen is allowed to evolve from the specimen for 72 hr. The evolved hydrogen displaces mercury in the tube. Before taking the final reading of the evolved hydrogen, the specimen and tube are bounced slightly against the bottom of the jar to release any entrapped hydrogen bubbles in mercury. The volume of hydrogen evolved is measured to the nearest of 0.02ml or less. Height of mercury column inside the tube from the mercury level in the jar is also measured to an accuracy of 2mm. The specimen is then removed from mercury, cleaned and weighed nearest to 0.1 gm. Volume of hydrogen evolved from the weld is converted to the volume at standard temperature and pressure (STP), using the following equation.

$$VH = \frac{273(P-H)}{(273+T)760} V \text{ where}$$

T = gas column temperature in °C

P = barometer pressure in mm

V = measured volume of gas in eudiometer

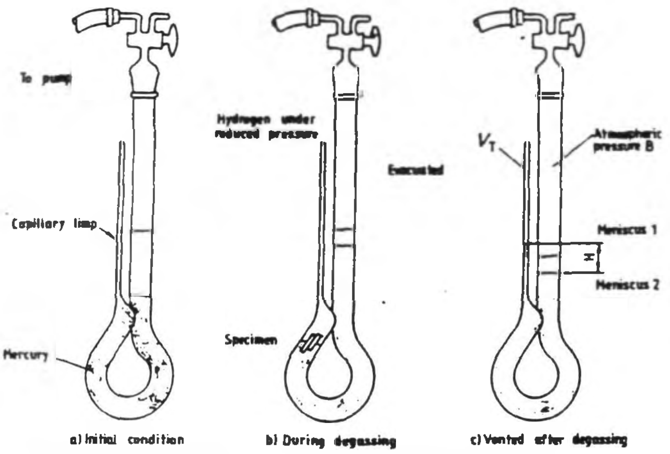
H = head of mercury (mm) at the time of measurement

VH= Volume of hydrogen gas converted to STP

From the weight of the deposited metal and VH, the hydrogen evolved for 100gm of weld metal is estimated and reported.

The apparatus recommended by IIW method for measuring diffusible hydrogen is shown in **Fig. 7**. It is basically a Y-tube containing mercury with one of the limb open and the other closed. The sample is introduced into the open limb and kept above the mercury column using a magnet. The limb is then evacuated to a pressure of 0.1 mm mercury to remove any moisture from the specimen. With the help of a magnet, the specimen is then transferred into the closed tube provided with a standard bore tube of small diameter at the top as shown. The sample floats in the closed limb allowing diffusible hydrogen to be collected in the standard bore tube. The whole procedure should be done as quickly as possible taking not more than two minutes. The Y-tube is stored at room temperature for 72 hr. When the evolution of hydrogen is complete, air is admitted into the open limb of the Y-tube. The mercury level rises in the closed limb to confine hydrogen with the standard bore tube. Length of the hydrogen gas column (C) and the head of the mercury (H) are measured in mm using a catheometer. Room temperature (T°C) and barometric pressure (P) are recorded. The volume of the hydrogen collected (V), corrected to standard temperature and pressure, is given by

$$V = \frac{273(P-H)(r^2C)}{760(273+T)1000} \text{ ml}$$



a) Initial condition b) During degassing c) Vented after degassing

Fig. 8 : Schematic of Diffusible Hydrogen Measurement Set Up as Per ISO and DIN Specifications [5]

where r is the radius of the standard bore tube.

The sample is removed from the mercury, cleaned and weighed to 0.01 g and weight of the deposited metal is determined and the amount of hydrogen evolved for 100 gm of deposited metal is found out. For reporting data as diffusible hydrogen / 100 gm of the fused metal, cross sectional area of deposited metal and the fused metal are measured on either ends of the specimen and to calculate total weight of the used metal, the gain in mass is multiplied by the average ratio of weld area to deposit area.

Both ISO and DIN standards recommend the same apparatus for measurement of diffusible hydrogen and this is shown in **Fig. 8**, Specimen is transferred to the wider limb of the apparatus. The limb is then connected to a vacuum pump to evacuate it to 10Pa. The specimen is then transferred to the narrow limb and allowed to degas for 72 hr. When degassing is complete, the wider limb is opened to the atmosphere. and the volume of hydrogen collected in the narrow tube (V_T) in cm^3 and the difference in the levels of mercury columns in the two limbs (H) in mm are measured. Knowing the mass of the weld metal (M) in gm, the (H_D) content for 100 gm of weld metal is estimated using the following formula.

$$H_D = \frac{\left(B - \frac{1,013}{760} H\right) V_T}{M} K$$

where B is atmospheric pressure in bar and

$$K = \frac{100 * 373}{1.013(273+t)}$$

where t = room temperature in °C

In order to estimate the HD per 100 gm of the fused metal, area of cross section of the deposited metal, a, and that of the fused parent metal, b, are found out. Then $H_{D(FM)}$ is estimated from the following relation.

$$H_{D(FM)} = H_D \frac{a}{a + b}$$

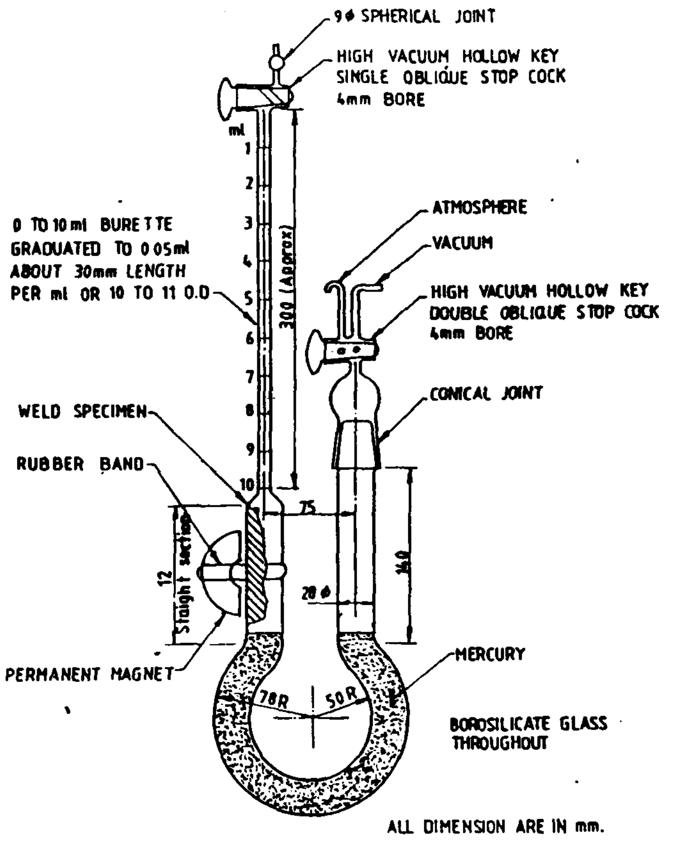


Fig. 9 : Schematic of Diffusible Hydrogen Measurement Set Up as per BIS Specifications [7]

Fig. 9 shows the schematic of the diffusible hydrogen meter as per BIS. Initially mercury is drawn into the burette up to the level of stop-cock and the stop-cock is closed. The sample is then introduced into the wide end tube of the meter and transferred to the narrow end tube with the help of a magnet as shown in the figure. The wide end tube is then connected to vacuum pump and the mercury level in both the limbs of the meter is leveled as shown in the Fig. 9. Sample is held in position 25mm clear off the mercury level. Hydrogen is allowed to evolve from the sample for 72 hours at 25±10°C. After the evolution is complete, the stop-cock at the wide end of the tube is slowly opened to the atmosphere and pressure above the mercury column in this limb is brought to atmospheric pressure. During this operation, mercury level in the narrow limb of the meter rises into burette. When the mercury has settled down, reading corresponding to the lowest meniscus of the mercury is measured nearest to 0.05ml. to obtain the hydrogen evolved from the sample. This is then converted to STP and reported as ml of hydrogen evolved for 100 gm of the weld metal using the following equation.

$$V_h = \frac{V_g(B-H)}{760} * \frac{273}{(273+T_R)} * \frac{100}{(M_2-M_1)}$$

V_h = Volume of diffusible hydrogen in ml per 100 gm of the deposited metal at NTP

V_g = Volume of gas in burette in ml after 72h

B = Barometric pressure in mm Hg

H = Head of mercury mm at which V_g is measured

M_2 = Mass of the sample in g after deposition of weld

M_1 = Mass of the sample in g before the deposition of the weld

Glycerin Method

This method is similar to that of mercury method and the main difference is that glycerin is used as the collecting fluid. The health hazards associated with the use of mercury led to the use of this method as an alternative technique for H_D measurement. It uses a single specimen of dimension 12x35x125 mm (12x25x125mm as per BIS) which includes weld start and stop. After welding the specimen is cleaned and transferred to measuring equipment within 70 secs. It is kept immersed in glycerin at 45±3°C for 48 h. and the hydrogen evolved from the sample is collected in a eudiometer as done in the case of mercury method. The apparatus used is very similar to that used for mercury method as per AWS standards. Many Shipping Classification Societies recognize this method and is also known as ABS method [8]. H_D values measured using this technique are found to be consistently lower than those obtained using mercury method [12]. This may be due to the dissolution of some part of the evolved hydrogen in glycerin. Another reason may be lower time (48hr.) given for evolution of hydrogen from the sample than that (72hr.) given for Mercury Method. The following formula has been recommended by JIS to convert the H_D value obtained using glycerin method to corresponding value using mercury method [11].

$$H_{D(Mercury)} = 1.27H_{D(Glycerin)} + 2.19$$

However, BIS recommends a slightly different formula as given below

$$H_{D(Mercury)} = 1.562H_{D(Glycerin)} + 1.453$$

Further, the analysis of gas collected over glycerin column of the eudiometer has been shown to contain oxygen and nitrogen in addition to hydrogen. Glycerin also absorbs water vapor from atmosphere and thus gets contaminated very easily. A critical evaluation of this test after carrying out many experiments concluded that the glycerin test is not a reliable method for measuring weld metal diffusible hydrogen content. Results are dependent upon conditions which are not normally controlled as test conditions such as environmental humidity and glycerin contamination etc. and the relationship between actual diffusible hydrogen content and the volume measured is not established [12].

Gas Chromatography

Use of Gas Chromatography (GC) for measuring diffusible hydrogen was originally developed at E.O. Paton Electric Welding Institute [13]. GC essentially consists of a gas separation column and a thermal conductivity detector (TCD). Gas separation column separates the various gases in a gas mixture based on their differences in the absorption and desorption characteristics and the TCD detects the gases based on their difference in thermal conductivity. Gas mixture to be analysed is introduced into GC by mixing it with a carrier gas and for analysis of hydrogen, argon is used as the carrier gas. Calibration of the equipment using different known volumes of gas or known concentration of gas mixtures is essential for obtaining quantitative data.

For measuring H_D using GC, the specimen is collected in specimen chamber after welding. The specimen chamber is then flushed and filled with argon. Hydrogen is allowed to evolve in this chamber at specified temperature for specified time. It can be 72 hr. at room temp. or 45°C as specified for mercury method or 6 hr. at 150°C. When hydrogen evolution is complete, the chamber is connected to GC and the amount of hydrogen present in the chamber is determined.

The facility to measure H_D using this instrument can be set up either to measure the concentration of hydrogen in the specimen chamber or the total volume of the hydrogen present in the chamber. If only concentration is measured, it is required to know the volume of the specimen chamber and the pressure of the gas mixture inside the chamber accurately to estimate the total volume of hydrogen evolved. In this method, a known volume of the gas mixture from the specimen chamber is injected into the carrier gas stream of the GC which is calibrated using argon - hydrogen mixtures of various concentrations. From the calibration curve the concentration of hydrogen in the chamber can be determined. A schematic diagram of this set up which uses a gas sampling valve for gas injection is shown in **Fig. 10**. The experimental details of measuring diffusible hydrogen by this method have been described by Quintana and Dannecker [14]. The main advantage of this technique is that the measurement can be repeated a number of times as only a small volume of gas is used every time for measurement. As gas injection can be done either using an

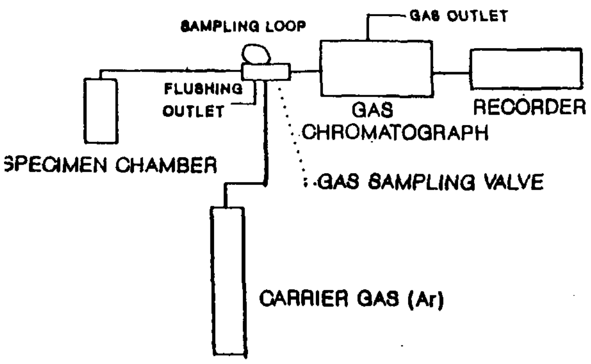


Fig. 10 : Schematic of Diffusible Hydrogen Measuring Set Up using Gas Chromatograph (for measurement of concentration)

injection port which is provided in commercially available GCs or using a gas sampling valve which is readily available as an accessory, any GC with molecular sieve as the column material and TCD as the detector can be used for this purpose with no modification. As argon gas has to be filled at higher pressures than the ambient for repeated injection of the gas mixture into GC, the concentration of hydrogen in the gas mixture will be generally low. Only a small volume (1-5ml) of this gas mixture is introduced into the GC and this gets further diluted by the carrier gas. Hence, if the concentration of hydrogen in the carrier gas after sample injection, is below the minimum limit of the detector it is not possible to carry out the measurement. However, it may be noted that the difference in the thermal conductivity of argon and hydrogen is appreciable and it is possible to measure a hydrogen concentration in 10 ppm range by this method.

For measurement of total hydrogen evolved from sample directly by GC, it is required to introduce the specimen chamber in one of the two carrier gas streams of the GC so that carrier gas flows through the chamber to the GC, thus carrying along with it all the gas present in the chamber. However, initially it is required to isolate the specimen chamber from the carrier gas stream till the equipment stabilizes and is ready for measurement. For achieving this requirement of isolating the specimen chamber before measurement and introducing it into the carrier gas stream at the time of measurement, without resulting in atmospheric contamination of the carrier gas, the chamber should be equipped with special multiport valves. A schematic of this measuring set up using a four way valve is shown in **Fig.11**. In one mode of operation of the valve, carrier gas flows straight into the GC and in other mode it flows through the gas sampler to GC. As the whole gas inside the chamber is taken to GC, it gives a signal corresponding total hydrogen present in the chamber. If the equipment is calibrated for different volumes of hydrogen, total volume of hydrogen evolved from the sample can be directly measured. The major limitation of this technique is that only one measurement can be carried out. However, it is not required to known the volume of the specimen chamber and the pressure of the gas. As total gas inside the chamber is taken into the detector, reliable measurements can be carried out even if the hydrogen evolved from the sample is very low. Dedicated GC provided with gas samplers fitted with suitable multiport valves is commercially available and is being widely used for measuring diffusible hydrogen.

As collection of hydrogen evolved from the sample is carried out in a separate chamber filled with argon, it is possible to carry out the collection of hydrogen evolved from the sample at higher temperatures. This would in turn reduce the time needed for the complete evolution of hydrogen and thus making it possible to carry out the measurement within a shorter duration than if the mercury or glycerin methods are used. It has been found that time given for hydrogen evolution can be reduced to 6hrs. if the specimen is heated to 150°C so that hydrogen content in the weld can be obtained within a day of welding [14].

The above description of the different methods of measuring diffusible hydrogen indicates that there are only two reliable methods namely; mercury and GC methods recognized by different standards [2-7, 11] to measure diffusible hydrogen in welds. Among these, mercury method is the most popular one and it is very easy to set up. However, due to the health hazards associated with the use of mercury, Gas Chromatography method, as an alternative technique, is being accepted by many standards. It is also possible to complete the measurement at much shorter time than that is required for mercury method. Glycerin method, though approved by some standards [6,9,10] has been proved to be inaccurate and not considered as a reliable method.

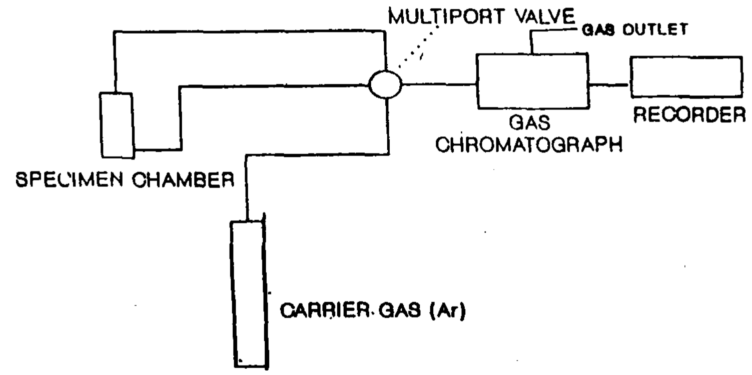


Fig. 11 : Schematic of Diffusible Hydrogen Measuring Set Up Using Gas Chromatograph (for measurement of total hydrogen)

COMPARISON OF INDIAN STANDARD WITH OTHER STANDARDS

A comparison of the method specified by BIS with those of the others reveals that the specifications of BIS are insufficient and need modifications to make it comparable with ISO, AWS or DIN, the most widely used standards by the welding community all over the world. At present BIS is confined to SMAW and silent about the H_D measurement in other welding methods. As other welding methods like SAW, GMAW and FCAW, are becoming increasingly popular, it is required to include welding procedures for measuring diffusible hydrogen from the welds made by these processes too in the BIS. AWS specification contains procedures for SAW and although ISO specification does not cover these welding processes, IIW method from which this has been derived provides detailed welding procedures for SAW and GMAW processes. Similarly procedure for SAW is also included in DIN standard.

BIS permits both mercury and glycerin methods for measuring diffusible hydrogen; but does not cover Gas Chromatography method. This method is being widely used in US and Japan and has been incorporated into the standards of these countries. GC method has definite advantage over mercury method in that measurement time can be reduced by carrying out hydrogen evolution at higher temperatures. It is also free from health hazards associated with the mercury methods. Hence it is also required to include GC method in the BIS specification for diffusible hydrogen measurement. Further, as it has been shown that the H_D values obtained from glycerin method are lower than that of the mercury method and uncertainities exist in the reliability of the values measured, this method may even be dropped from the BIS specification.

CONCLUSIONS

This report gives details of different International Standards available for measuring diffusible hydrogen in weld metal. It compares these standards with BIS and recommends the following modifications in the present specification of the BIS.

1. Inclusion of welding procedures for SAW, GMAW and FCAW for measuring diffusible hydrogen in the weld made by these processes.
2. Inclusion of GC method as an additional method for measuring diffusible hydrogen in the weld.
3. Removal of glycerin method from the present BIS standard.

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