

STUDY OF CORROSION PROPERTIES ITER IN-WALL SHIELD (IWS) FASTENERS AND STRUCTURAL INTEGRITY OF IWS

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Abstract

In-Wall Shield (IWS) Blocks will be inserted between inner and outer shell of ITER Vacuum Vessel. These blocks comprise of number of plates of Stainless Steel stacked together using fasteners of XM-19 and M30 size. Plates are tightened with pretension of 107 kN to withstand EM force of 1.83×10^4 N during ITER operation. These bolts are spot welded with blocks to lock any type of rotation. There are approximate 1500 such bolts exposed to vacuum in one vessel sector with approximate surface area of 70.5 m². The surface condition of these fasteners play an important role while leak testing of VV. XM-19 material is highly corrosion resistant but, if the fasteners are exposed to normal or humid environment for a long time its surface may get oxidised and catch the corrosion which may impact the ITER operation in three ways: (a) Reduced Structural Integrity of blocks (b) Gas load due to outgassing (c) Generation of corrosion products in Cooling Water System. This corrosion has been assessed by (a) Measuring the Corrosion rate (CR) of XM-19 fasteners (exposed in natural environment with normal humidity) and (b) XM-19 washer exposed to water with ITER operating temperature and pressure. This study is carried out using Scanning Electron Microscope (SEM) and Electrochemical Polarization Technique. For SEM analysis, samples were polished and corrosion depth was measured and accordingly CR was calculated. In Electrochemical Polarization Technique, samples were induced with corrosion at room temperature and high temperature in water medium. Pt electrode was used as cathode and Ag-AgCl₃ as reference electrode. CR was calculated with the help of corrosion current. Tafel curves of corroded samples show that, reverse polarization path do not intersect the forward path and indicate no tendency of pitting corrosion. Maximum corrosion observed by using Tafel curve is 0.1067 mpy. Outgassing rate of naturally corroded XM-19 bolt was measured 6.06 E-8 Pam³s⁻¹m⁻² which is less than the acceptable limit for IWS. Total corrosion product for one Vessel sector was calculated with the help of CR and surface area in one vessel sector and found 3.20 Kg/year. It can be removed by appropriate filters. Study shows that corrosion and out gassing properties of corroded XM-19 fasteners are acceptable for ITER IWS. Detailed experimental set up and results of corrosion study will be presented in the paper.

1. INTRODUCTION

IWS blocks will be installed between the walls and it is not possible to maintain them after the assembly of torus. Structural Integrity of IWS blocks mainly depends on the components which are used to fasten the plates together forming a block i.e. fasteners. Corrosion is the key issue which may impact the strength of fasteners as well as blocks. There is a very large time gap between the procurement of fastener's material and final assembly of IWS blocks fastened with these fasteners. Hence, it is necessary to make sure that, if there is any corrosion in fasteners it doesn't affect the operation of ITER.

During ITER operation phase, there will be various kind of loads will be generated on IWS Blocks [1] e.g. Dead Weight, Tensile Load, Torque and Electromagnetic Load. Worst combination of various forces leads to maximum force which will be transferred to the vessel through IWS blocks. Maximum electromagnetic force going to be generated on IWS blocks will be 1.83×10^4 N. Due to the electromagnetic force, current will be generated which may create the repulsive force in plates on IWS blocks. This repulsion may lead to displacement of IWS plates. If bolts are not strong enough, IWS block may fall apart in between the walls of Vacuum Vessel. To withstand these forces, an appropriate value of pretension (107kN) is applied on bolts for fastening the IWS blocks. There are approximate 1500 such bolts of XM-19 material in one Vessel Sector. These bolts will fasten the block on both the edges and hence called as lateral bolts (Fig. 1). There are another type of fasteners i.e. cap-screw which are used to fasten the blocks with vessel. Approximate value of pretension to be applied on cap-screws is 23kN. Due to the larger length, surface area of lateral bolts dominates among other fasteners.

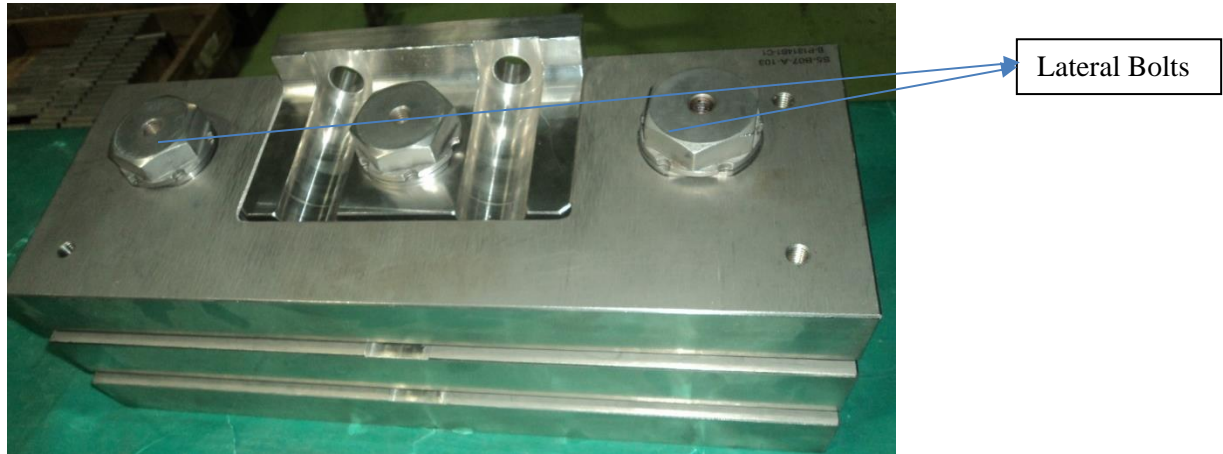


Fig.1 Lateral Bolts in IWS Block

These lateral bolts will be spot welded with blocks to lock any type of rotation during ITER operation. XM-19 material has been chosen for manufacturing of IWS bolts because of its excellent corrosion resistance and high yield strength. Approximately 70.5 m² surface area in form of these bolts will be exposed to vacuum during leak test of ITER vacuum vessel. If these fasteners are exposed to natural or humid environment for a very long time, surface may get oxidised (Figure-2) and catch the corrosion which may affect the structural integrity of IWS Blocks in following ways:



Fig.2 IWS fasteners in oxidised condition

2. EFFECT OF CORROSION ON STRUCTUAL INTEGRITY

Structural integrity of IWS blocks very much depends on the strength of bolts as the bolts are the maximum stress bearing components in IWS blocks. Any corrosion attack on bolts may affect its integrity. In the present study

samples from various locations of corroded IWS bolts and washer have been taken and impact of corrosion was evaluated by studying the following aspects:

2.1 Corrosion Rate

Three type of samples were prepared to measure the corrosion rate. Total ten samples were prepared from bolts corroded in natural environment for the period of approximate 2 years. Three samples were prepared from the washer of XM-19 exposed to ITER operating conditions (OC) mentioned in Table-1. Special facility was developed for this purpose [2].

TABLE-1

Operating Condition	Description	Duration
OC1	Temperature-100°C, Pressure-1.1 MPa	5 Days
OC2	Temperature-100°C, Pressure-1.1 MPa	5 Days
OC3	Temperature-100°C, Pressure-1.1 MPa	5 Days

Above sequence has been followed three times. Water used in above mentioned operating conditions had Chloride concentration level of 1000 ppb and Hydrogen Peroxide of 2ppm (referred as W1000 HP water). This particular water chemistry will be used in ITER operation. A schematic diagram of the system to obtain above operating conditions is shown in Fig. 3. Sample was mounted in an autoclave made of SS304 material. Test solution was filled by opening the inlet valve of autoclave and then pressurizing the autoclave up to the required pressure in OC1 and OC2 with the help of pump.

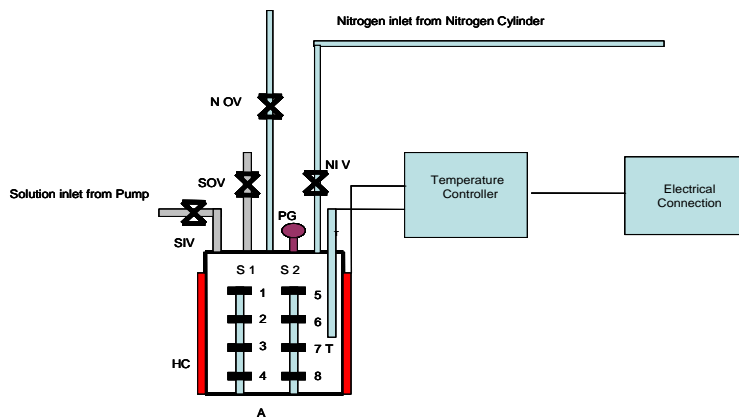


Fig.3. Schematic Diagram of Corrosion of Washer in ITER operating conditions

- NIV: Nitrogen gas inlet Valve
- NOV: Nitrogen gas Outlet Valve
- A: Autoclave, HC: Heating Coil
- SIV: Solution Inlet Valve
- SOV: Solution Outlet Valve
- PG: Pressure Gauge,
- T: Thermocouple

Three samples were prepared from fresh machined material without any corrosion. Corrosion rate was measured by using following techniques:

2.1.1 Measurement of corrosion depth

Total six samples which were corroded in natural environment and one sample corroded in ITER operating conditions, were cut and polished in order to examine the corrosion depth. With the help of Scanning Electron Microscope (SEM), the depth up to which corrosion has attacked was measured. Corrosion rate has been calculated with the help of corrosion depth and the duration in years over which the corrosion has occurred.

Results

The corrosion depth measured and averaged over seven samples up to which corrosion has affected the material is 11.66 Micron. Some of the examples of SEM images of corroded part of fasteners are shown in Figure-4. This corrosion has occurred in 2 years after manufacturing. Hence, the Corrosion Rate calculated per year comes out to be 0.229 mpy.

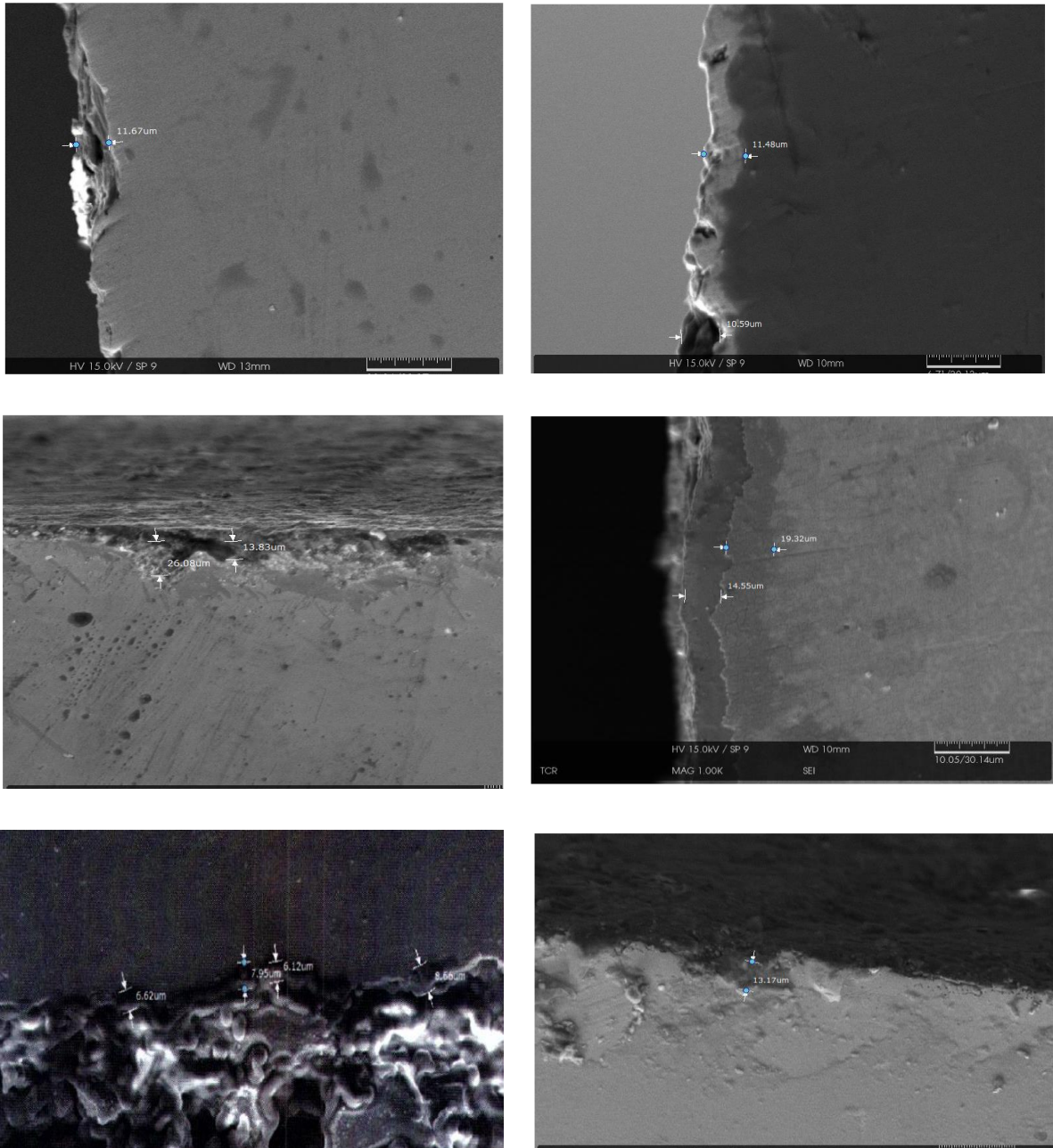


Fig.4 SEM images of corroded part of fasteners

2.1.2 Electrochemical polarization technique

Corrosion rate has been calculated using Electrochemical Polarization Technique. To perform this test total six samples were prepared out of which total four samples were from the bolts corroded in natural environment and 2 samples corroded in ITER operating condition. This test was performed on room temperature as well as elevated temperature ~ 80°C. Water with stagnant condition was used as test solution. Cyclic Polarization curve was plotted to characterize the susceptibility of material to pitting corrosion (Fig. 5). These curves of corroded samples show that, reverse polarization path do not intersect the forward path and indicate no tendency of pitting corrosion. By combining the Tafel equations for cathodic and anodic reaction, Butler Volmer equation is generated. The numerical result obtained by fitting corrosion data to a model is generally the corrosion current with the help of which corrosion rate is determined by using software.

$$I = I_{\text{corr}} \left(e^{2.303(E - E_{\text{corr}})/\beta_a} - e^{-2.303(E - E_{\text{corr}})/\beta_c} \right)$$

Corrosion rate (CR in mpy) = $0.13 \times I_{\text{corr}} W/d$

W is equivalent weight in gm

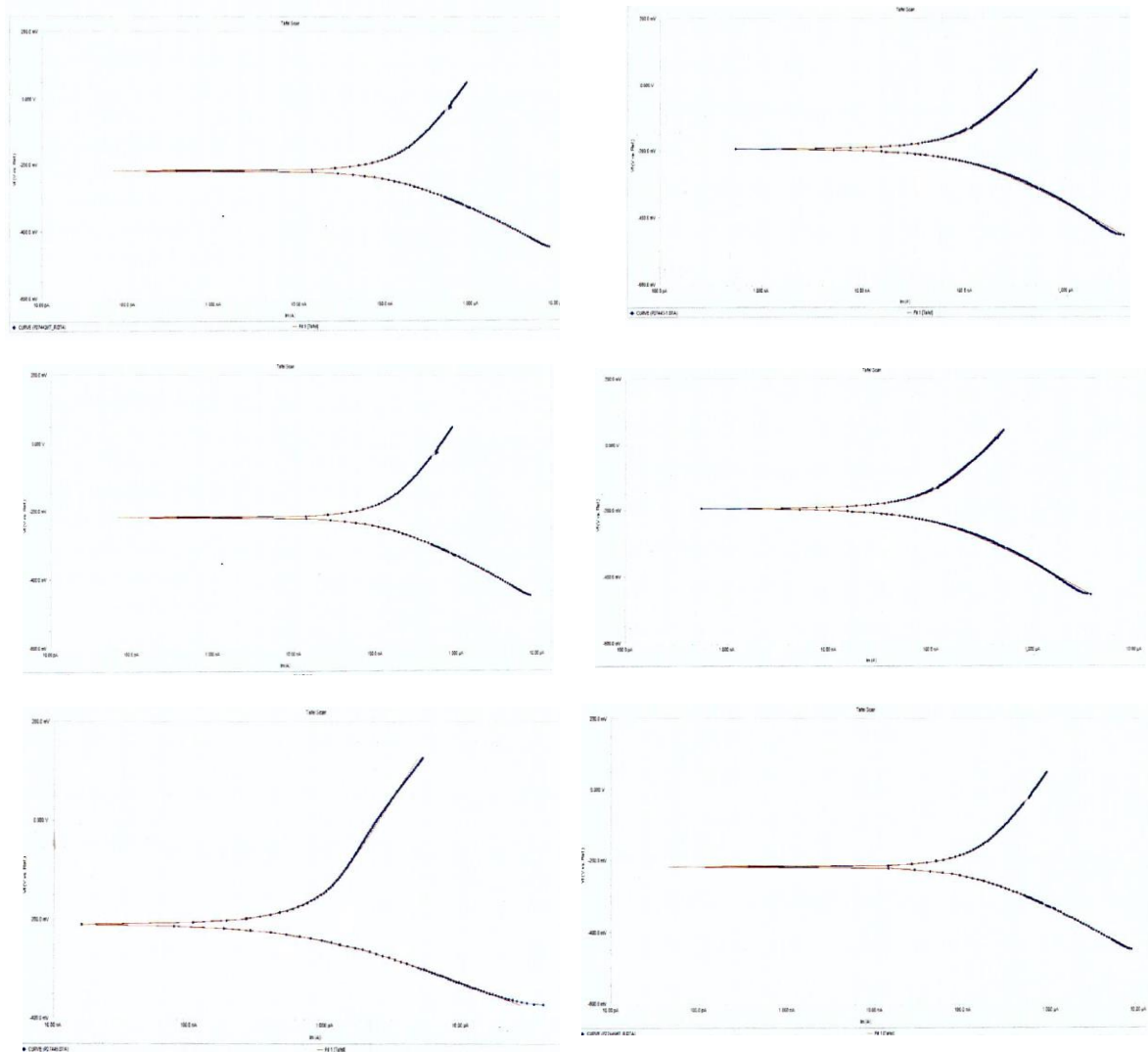


Fig. 5. Polarization Curves for Corroded fasteners on Room Temperature and Elevated Temperature

Results

Average corrosion rate at room temperature for the samples exposed in natural environment is 0.0745mpy while for elevated temperature corrosion rate for these samples is 0.209mpy. Whereas the corrosion rate of washer exposed to ITER temperature and pressure is measured 0.0798 at room temperature and 0.01508 at elevated temperature. These rates are lower than the corrosion rate of fresh machined sample of XM-19 subjected to the

electrochemical Polarization with the ITER temperature, Pressure and water chemistry for a period of 75 days. Hence, the corrosion occurred due to exposure in natural environment is not a threat.

2.2 Generation of corrosion products

There are chances that corrosion occurred in these bolts may interact with water (flowing between inner and outer shells of vacuum vessel for heating and cooling) and may change the water chemistry. Also, it can add insoluble impurities in water. Total Surface Area occupied by these bolts is approximately 1/22nd time of the total surface area of IWS in one Vessel Sector. According to present Corrosion Rate, corrosion product of XM-19 from these bolts in one year will be approximate 3.64 Kg while on the other hand being highly corrosive material or occupying large surface area other IWS Materials will contribute to the impurities in water much more than that of XM-19. Corrosion Products of all the IWS materials per sector per year are shown in Fig-6 and table-1. These products can be removed from water by appropriate filtering system.

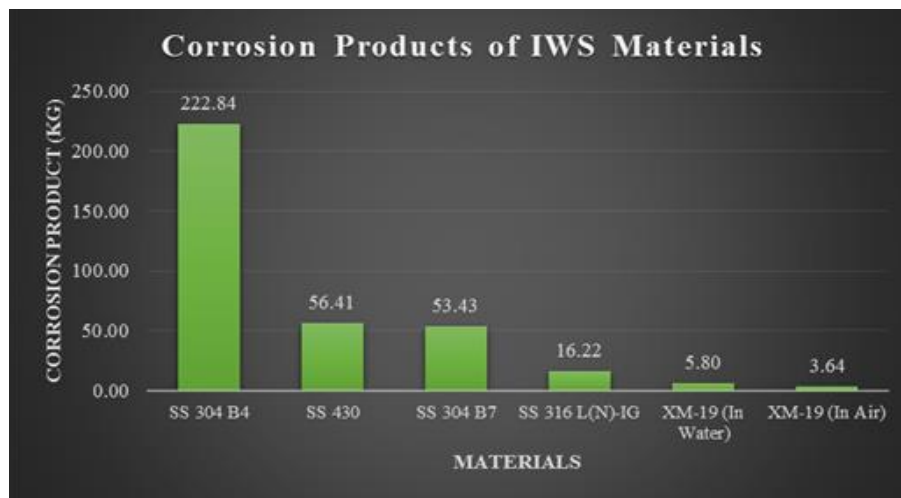


Fig-6 Corrosion Products of IWS

3. EFFECT OF CORROSION ON OUTGASSING RATE

Although IWS blocks will be submerged in water passing through the double wall of VV, Outgassing Rate of IWS materials plays a significant role in leak detection. On a leak detector there will be a spill-over of mass 3 and mass 2 to mass 4 which creates a background reading. Helium background will have contribution of Hydrogen too. So it is necessary to ensure the low OGR of Hydrogen. To achieve an effective leak test it is required to obtain a background below $1 \times 10^{-9} \text{ Pam}^3\text{s}^{-1}$. Hence giving a maximum hydrogen Outgassing Rate $1 \times 10^{-7} \text{ Pam}^3\text{s}^{-1}\text{m}^{-2}$ for IWS at Room Temperature is the requirement for IWS materials. Outgassing Rate depends on absorption and adsorption of gases which is related to Surface Roughness. Surface Roughness of fasteners may get changed after corrosion and subsequently Outgassing Rate will also get affected. Water flowing between the walls of VV will promote the corrosion of IWS. IWS is not accessible until life of the machine after closing of Vacuum Vessel so it is necessary to examine the effect of this corrosion on Outgassing Rate.

Outgassing rate of one of the bolt which was corroded in natural environment has been measured by using the same technique which is being used to measure the Outgassing Rate of IWS Materials.

3.1 Experimental Setup for Outgassing Rate Measurement

A system with known conductance has been used to measure the Outgassing rate of corroded IWS bolt (Fig. 7). This system measures the total gas load due to thermal out-gassing and composition of various gases evolving from the sample when exposed to different baking temperatures as a function of exposure time in vacuum. Material of system is SS 304 L. Complete system is baked up to 200°C. The acceptance limit Outgassing rate of IWS materials as per In Wall Shielding Procurement Arrangement is $< 1 \times 10^{-7} \text{ Pam}^3\text{s}^{-1} \text{ m}^{-2}$ [Ref.3].

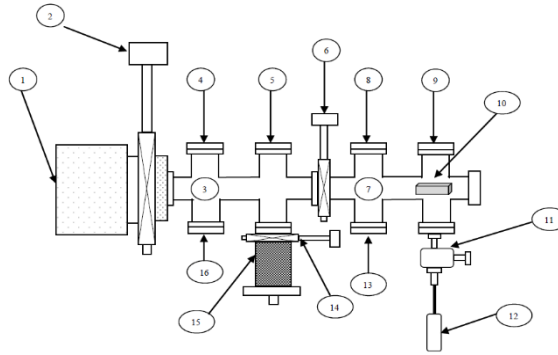


Fig. 7 Schematic Diagram of Outgassing System

- 1) Ion pump 2) UHV Gate Valve 3) Pumping chamber 4) Pressure Gauge (Range: 1000 mbar to 1×10^{-9} mbar) 5) Residual Gas Analyzer (Range: 1 – 200 amu) 6) UHV Gate Valve 7) Sample chamber 8) Pressure Gauge (Range: 1000 mbar to 1×10^{-9} mbar) 9) Feed through for Temperature Measurement 10) Sample coupon 11) Variable leak valve 12) Pressure gauge (Range: 2 bar to 1×10^{-2} mbar) 13) Extra port for venting valve 14) UHV Gate Valve 15) Turbo molecular pump 16) Extra port

3.2 Principle

The basic parameter measured in the system is gas load. The gas load is measured by measuring the pressure different across a known conductance. The system measures the flow of the gas evolving from the sample material due to Thermal Out-gassing and the specific Thermal Out-gassing rate Q_{th} is given by

$$Q_{th} = C \Delta P/A$$

Where, C = Known conductance (l/s)

ΔP = Pressure difference across the conductance (mbar)

A = Area of the desorbing surface – measurable physical area of the sample (cm²)

The measured Outgassing rate is the net rate of the difference between the intrinsic Outgassing Rate of the surface and the readsorption rate [Ref.4].

3.3 Results

Measurement shows the Outgassing Rate of corroded bolt $6.06 \text{ E}^{-8} \text{ Pam}^3\text{s}^{-1}\text{m}^{-2}$ which is less than the acceptable limit. Hence, this corrosion due to environmental exposure is not going to affect the Vacuum Quality while Leak Testing.

4. CONCLUSION

Corrosion rate of IWS fasteners which are exposed in air for a very long and got corrode was measured with the help of Scanning Electron Microscope as well as by using electrochemical polarization technique. Impact of this corrosion is very less compared to the corrosion which is going to take place in other IWS materials when it will be exposed to ITER operating conditions. Amount of corrosion occurred naturally in the fasteners is not going to lead any difficulty while detecting the leak in Vacuum Vessel. Hence, the natural corrosion occurred in IWS bolts during the cycle of manufacturing and assembly is not a threat to operating conditions of ITER.

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