Journal of Steel Structures & Construction
ISSN: 2472-0437

Krasikov, J Steel Struct Constr 2016, 2:2
DOI: 10.4172/2472-0437.1000122

Research Article

Open Access

Alloying of Steel and Graphite by Hydrogen in Nuclear Reactor

Evgenii Krasikov*

National Research Centre Kurchatov Institute 1, Kurchatov Sq, Moscow 123182, Russia

Abstract

In traditional power engineering hydrogen may be one of the first primary sources of equipment damage. This problem has high actuality for both nuclear and thermonuclear power engineering. Study of radiation-hydrogen embrittlement of the steel raises the question concerning the unknown source of hydrogen in reactors. Later unexpectedly high hydrogen concentrations were detected in irradiated graphite.

It is necessary to look for this source of hydrogen especially because hydrogen flakes were detected in reactor vessels of Belgian NPPs.

As a possible initial hypothesis about the enigmatical source of hydrogen one can propose protons generation during beta-decay of free neutrons поскольку inasmuch as protons detected by researches at nuclear reactors as witness of beta-decay of free neutrons.

Keywords: Nuclear reactor; Steel; Graphite; Source of hydrogen

Introduction

It is known that in traditional power engineering hydrogen may be one of the first primary sources of equipment damage [1]. This problem has high actuality for both nuclear and thermonuclear power engineering [2]. Particularly reactor pressure vessels (RPV) of the WWER-440/230 project were manufactured without stainless cladding that is were in contact with primary circuit water and accessible for hydrogen as a product of RPV wall corrosion. Analysis of the combined radiation-hydrogenation embrittlement of the 48TS type vessel steel was performed in [3] where at the mention of the American [4] and own data question concerning unknown source of hydrogen in metal that was irradiated in nuclear reactor in hermetic ampoules (was named as "irradiation-produced hydrogen" (IPH) was raised.

Materials and Methods

Table 1 lists chemical composition of the RPV steel used (48TS type). A-543 type US steel takes for comparison.

4% solution of H_2SO_4 was used for additional electrolytic hydrogenation of the specimens (current density 0,1A/cm^2).

Hydrogen concentration was determined by thermal degasation method at temperatures up to 1000°C with gas chromatograph (thermal conductivity detector) registration of gas released.

Experimental Results and Discussion

Determination of the hydrogen content in the irradiated steel fulfilled in the USA went to unexpected result: hydrogen content noticeably exceeded the quantity rated at (n,p) transmutation reaction: less than 0,1 ppm.

Results of the IPH concentration in steel analysis carried out in the USA are shown in Table 2 [4]. One can see that the greater the fast neutron fluence (FNF) the greater the hydrogen content.

Ageing of the steel at 100-325°C during 48 h revealed that IPH is not diffusible up to irradiation temperature that is IRH are in the irradiation produced traps. Inasmuch as IPH at temperatures of mechanical tests was immovable indicated values were subtracted from total quantity of hydrogen measured.

Type	C	Si	Mn	P	S	Cu	Cr	Mo	Ni
48TS	0,16	0,30	0,43	0,014	0,011	0,11	2,75	0,67	0,16
A543	0,14	0,18	0,20	0,011	0,015	0,07	1,60	0,50	3,01

Table 1: Chemical composition of the RPV steels A-543 and 48TS (% % mass).

In I.V. Kurchatov Institute at several experiments was determined that steel specimens irradiated at relatively low (100-140°C) temperatures in sealed Ar contained ampoules hydrogen content was many times higher relatively initial content but was independent on FNF (Table 3) [3].

Degasation kinetics is plotted in Figures 1 and 2.

FNF, × 10^{18} cm^{-2}; $t_{irr.}$=225-300 °C	IPH concentration, ppm; $t_{degasation}$=1000°C
0	0,2
7	0,9
200	1,7
400	2,1

Table 2: Dependence of the IPH concentration in steel versus FNF (E>1 MeV).

FNF, × 10^{18} cm^{-2}; $t_{irr.}$=100-140°C	IPH concentration, ppm; $t_{degasation}$=300°C.
0	0,2
100	2,9
170	4,3
190	13,3
270	24,9
450	9,8
500	3,1

Table 3: Dependence of the IPH concentration in steel versus FNF (E > 0,5 MeV).

***Corresponding author:** Evgenii Krasikov, National Research Centre Kurchatov Institute 1, Kurchatov Sq, Moscow 123182, Russia, Tel: +7 499 196 99 61; E-mail: ekraikov@mail.ru

Received September 08, 2016; **Accepted** October 20, 2016; **Published** November 28, 2016

Citation: Krasikov E (2016) Alloying of Steel and Graphite by Hydrogen in Nuclear Reactor. J Steel Struct Constr 2: 122. doi: 10.4172/2472-0437.1000122

Citation: Krasikov E (2016) Alloying of Steel and Graphite by Hydrogen in Nuclear Reactor. J Steel Struct Constr 2: 122. doi: 10.4172/2472-0437.1000122

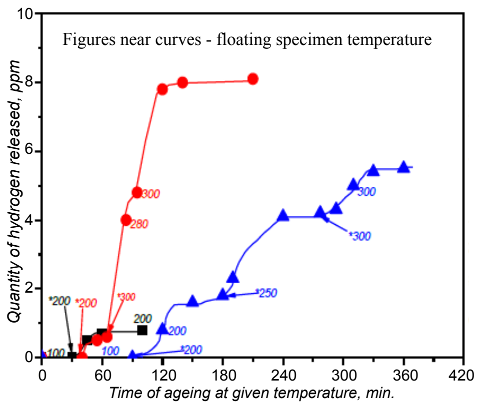

Figure 1: IPH degasation kinetics for irradiated steel (4,5 × 1020cm^{-2} at 140°C).

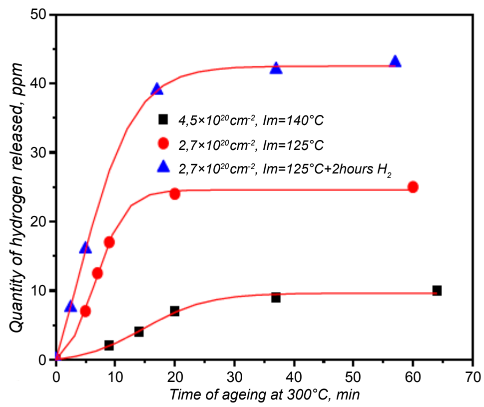

Figure 2: Hydrogen degasation kinetics for irradiated and irradiated+ hydrogenated steel.

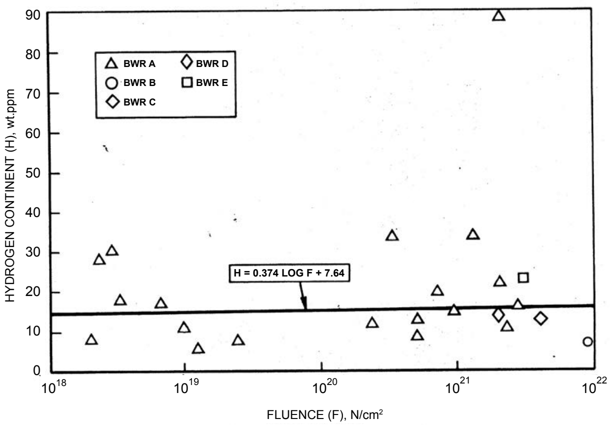

Figure 3. IPH content in 304 SS versus FNF (E>1 MeV).

As one can see from Figure1 that RIH discharge starts when heating temperature exceeds the irradiation temperature. It means that RIH is accumulated in radiation defects (traps).

Rather later data appear on unexpectedly high hydrogen concentrations in stainless steels irradiated in BWR type reactors (Figure 3) and high generations of hydrogen and helium in nickel [5,6].

FNF, cm^{-2} (E>0,5 MeV)	Irradiation temperature, °C	Quantity of hydrogen released, ppm		
		Degasation temperature, °C		Total
		1000	1800	ppm
0		2,2 1,5	4,2 2,9	6,4 4,4
1 × 10^{22}	500	20,8 49,7 41,2 19,5	- - 1342 864	20,8 49,7 1383 883
2 × 10^{21}	1100	- -	369 327	369 327

Table 4: Results of the thermal degasation of the GR-280 type graphite.

Surprisingly high hydrogen concentrations were revealed in irradiated graphite [7]. Table 4 presents the results of the thermal degasation of the GR-280 type graphite.

As it is seen hydrogen concentrations in irradiated specimens are one-two orders of magnitude higher than in unirradiated ones (Table 4).

It is necessary to look for enigmatic source of hydrogen especially because in frame of inspections numerous flows were detected in the forged rings of the reactor pressure vessels in the Belgian nuclear power plants Doel 3 and Tihange 2 [8,9]. The owner Electrabel claimed that flaws were "most likely" hydrogen flakes.

One of the unobvious but probable initial hypothesis on enigmatic source of the hydrogen in operating nuclear reactor is generation of protons as a product of beta-decay of free neutrons (lifetime ~15 min) [10].

References

1. Vainman AB (1990) Hydrogen embrittlement of the high pressure vessels. Kiev, Naukova dumka In Russian.
2. Alekseenko NN (1997) Radiation Damage of Nuclear Power Plant Pressure Vessel Steels. ANS pp: 97.
3. Krasikov EA (1974) Investigation of hydrogen embrittlement and hydrogen diffusion in irradiated steel, PhD Thesis, Moscow.
4. Brinkmann CR (1970) Effects of Hydrogen on the Ductile Properties of Irradiated Pressure Vessel Steels. ASTM International, Idaho Falls.
5. Jacobs AI (1987) Hydrogen buildup in Irradiated Type-304 Stainless Steel. ASTM STP 956. F.A. Garner, and N. Igata, Eds. ASTM, Philadelphia, pp: 239-244.
6. Greenwood LA, Garner FA, Oliver DM (2004) Surprisingly Large Generation and Retention of Helium and Hydrogen in Pure Nickel. Journal of ASTM International, 1: 529-539.
7. Biriukov AB, Krasikov EA (1998) Impact of neutron irradiation on graphite dehydrogenations. VANT, ser. NRC Kurchatov Institute, Moscow (In Russian) Thermonuclear fusion pp: 3-8.
8. Tweer I (2016) Flawed Reactor Pressure Vessels in the Belgian NPPS Doel 3 and Tihange 2. Comments on the FANC Final Evaluation Report.
9. Bass BR, Dickson TL, Gorti SB, Klasky HB, Nanstad RK, et al. (2015) ORNL Evaluating of Electrabel Safety Cases for Doel 3/Tihange 2 Final Report (R1).
10. Yu A, Mostoyoi (1996) Neutron yesterday, today, tomorrow. Successes of physics (UFN) 39: 987-1022.