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Radiation Annealing of the RPV Steel Radiation Embrittlement

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Abstract

Influence of neutron irradiation on RPV steel degradation are examined with reference to the possible reasons of the substantial experimental data scatter and furthermore - nonstandard (non-monotonous) and oscillatory embrittlement behavior. In our glance this phenomenon may be explained by presence of the wavelike component in the embrittlement kinetics. We suppose that the main factor affecting steel anomalous embrittlement is fast neutron intensity (dose rate or flux), flux effect manifestation depends on state-of-the-art fluence level. At low fluencies radiation degradation has to exceed normative value, then approaches to normative meaning and finally became sub normative. Data on radiation damage change including through the ex-service RPVs taking into account chemical factor, fast neutron fluence and neutron flux were obtained and analyzed. In our opinion controversy in the estimation on neutron flux on radiation degradation impact may be explained by presence of the wavelike component in the embrittlement kinetics. Therefore flux effect manifestation depends on fluence level. At low fluencies radiation degradation has to exceed normative value, then approaches to normative meaning and finally became sub normative. Moreover as a hypothesis we suppose that at some stages of irradiation damaged metal have to be partially restored by irradiation i.e. neutron bombardment. Nascent during irradiation structure undergo occurring once or periodically transformation in a direction both degradation and recovery of the initial properties. According to our hypothesis at some stage(s) of metal structure degradation neutron bombardment became recovering factor. As a result oscillation arise that in tern lead to enhanced data scatter.

Keywords

RPV steel, radiation embrittlement, radiation annealing

Introduction

As a main barrier against radioactivity outlet reactor pressure vessel (RPV) may be a key component in terms of NPP safety. Therefore present-day demands in RPV reliability enhance need to be met by all possible actions for RPV in-service embrittlement mitigation. Annealing treatment is understood to be the effective measure to revive the RPV metal properties deteriorated by neutron irradiation. There are two approaches to annealing. the primary one is so-called «dry» heat (~475°C) annealing. It allows obtaining practically complete recovery, but requires the removal of the reactor core and internals. External heat source (furnace) is required to hold out RPV heat treatment. the choice approach is to anneal RPV at a maximum coolant temperature which may be obtained using the reactor core or primary circuit pumps while operating within the RPV design limits. This coldness «wet» annealing, although it can't be expected to supply complete recovery, is more attractive from the sensible point of view in cases when the removal of the internals is impossible [1].

Materials and Methods

Table 1 lists chemical composition of the RPV steel used.

C	Si	Mn	P	S	Cu	Cr	Mo	Ni
0,14	0,34	0,59	0,009	0,013	0,08	2,10	0,91	1,15

Table 1: Chemical composition of the 15Cr3NiMo1V (%%mass)

RPV in-service embrittlement takes place as a law of nature. it's known, however, that along side radiation embrittlement neutron irradiation may mitigate the radiation damage [2].Therefore we've tried to check the likelihood to use the effect of radiation-induced ductilization in «wet» annealing technology by means of nuclear heat utilization as heat and neutron irradiation sources directly . In support of the above-mentioned conception the 3-year duration reactor experiment on 15Cr3NiMoV steel with preliminary irradiation at operating PWR at 270°C and following extra irradiation (87 h at 330°C) at IR-8 test reactor was fulfilled. Determination of the Transition Temperature Shift (TTS) on fast (E>0,5MeV) neutron fluence (FNF) dependence was received by means of the quality Charpy specimens impact testing.

Experimental Results and Discussion

Radiation embrittlement kinetics at preliminary irradiation up to ~1020cm-2 and result of the following extra irradiation are plotted in Figure 1.

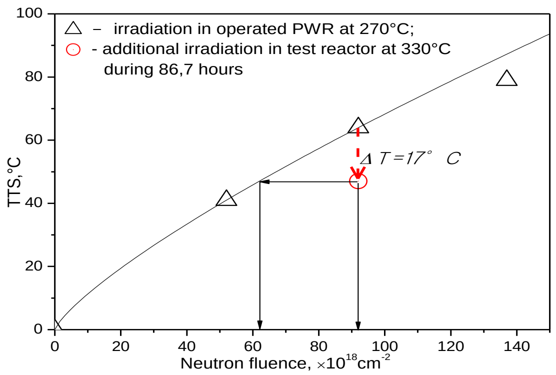

Figure 1: RPV steel TTS dependence on neutron fluence at preliminary irradiation up to ~1020cm-2 with following extra irradiation at heightened temperature

It is known that for RPV steels there's no recovery effect up to annealing and irradiation temperature difference of 70°C [3]. In our case one can see that actually embrittlement is partly suppressed up to value like 1,5 fold neutron fluence decrease, although difference between annealing and irradiation temperature difference is merely 60°C. So an example of the radiation annealing of the radiation embrittlement during steel reirradiation at heightened temperature happen. Possible comprehensible explanation is as follows: the radiation-induced copper-rich precipitates nature (dimensions and concentration) alteration. Evidently, we've fixed phenomenon almost like observed in [4] where neutron irradiation in some range of doses improves the mechanical properties of the unirradiated low-carbon steel (Figure 2). it's seen that irradiation of unirradiated (initial condition) steel up to dose of ~2,0×1018cm-2 along side strengthening cause quite 2-fold ductility increase.

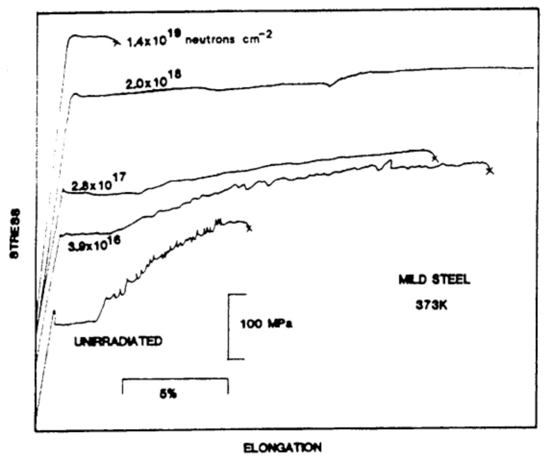

Figure 2: Stress-strain curves of mild steel as a function of neutron fluence

Conclusion

It is hoped that radiation annealing of the RPV steel radiation embrittlement that is «wet» annealing technology will help provide a better management of the RPV degradation as a factor affecting the lifetime of nuclear power plants which, together with associated management methods, will help facilitate safe and economic long-term PWRs operation.

References

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