Radiation Annealing of the RPV Steel Radiation Embrittlement

Krasikov E

National Research Centre, Russia

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Abstract

As a main barrier against radioactivity outlet reactor pressure vessel (RPV) is a key component in terms of NPP safety. Therefore present-day demands in RPV reliability enhance have to be met by all possible actions for RPV in-service embrittlement mitigation. Annealing treatment is known to be the effective measure to restore the RPV metal properties deteriorated by neutron irradiation. There are two approaches to annealing. The first one is so-called «dry» high temperature (~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 carry out RPV heat treatment. The alternative approach is to anneal RPV at a maximum coolant temperature which can be obtained using the reactor core or primary circuit pumps while operating within the RPV design limits. This low temperature «wet» annealing, although it cannot be expected to produce complete recovery, is more attractive from the practical point of view in cases when the removal of the internals is impossible.

Introduction

Materials and Methods

Table 1 lists chemical composition of the RPV steel used.

C	Si	Mn	P	S	Cu	Cr	Mo	Ni
0,1	0,3	0,5	0,009	0,01	0,0	2,1	0,9	1,1
4	4	9		3	8	0	1	5

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

RPV in-service embrittlement takes place as a law of nature. It is known, however, that along with radiation embrittlement neutron irradiation may mitigate the radiation damage [2]. Therefore we have tried to test the possibility to use the effect of radiation-induced ductilization in «wet» annealing technology by means of nuclear heat utilization as heat and neutron irradiation sources at once. In support of the above-mentioned conception the 3-year duration reactor experiment on $15Cr_3NiMoV$ 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 Standard 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.

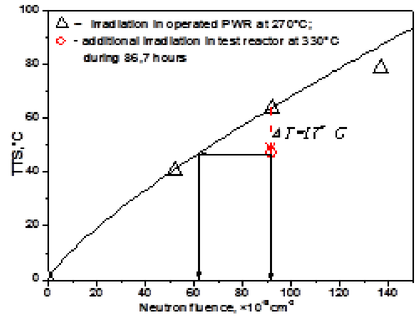

Figure 1: RPV steel TTS dependence on neutron fluence at preliminary irradiation up to ~1020cm^{-2} with following extra irradiation at heightened temperature

It is known that for RPV steels there is no recovery effect up to annealing and irradiation temperature difference of 70°C [3]. In our case one can see that in fact embrittlement is partly suppressed up to value equivalent to 1,5 fold neutron fluence decrease, although difference between annealing and irradiation temperature difference is only 60°C. So an example of the radiation annealing of the radiation embrittlement during steel reirradiation at heightened temperature take place. Possible comprehensible explanation is as follows: the radiation-induced copper-rich precipitates nature (dimensions and concentration) alteration. Evidently, we have fixed phenomenon similar to observed in [4] where neutron irradiation in some range of doses improves the mechanical properties of the unirradiated mild steel (Figure 2). It is seen that irradiation of unirradiated (initial condition) steel up to dose of ~2,0×1018cm-2 along with strengthening lead to more than 2-fold ductility increase.

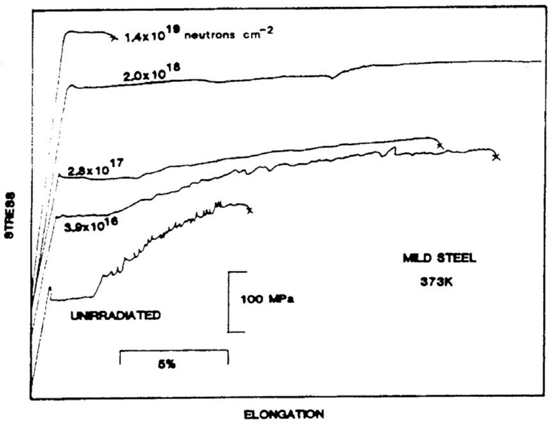

Figure 2: Stress-strain curves of mild steel as a function of neutron fluence

influence of nucleon irradiation on RPV steel degradation area unit examined with relevancy the attainable reasons of the substantial experimental information scatter and moreover - nonstandard (non-monotonous) and oscillating embrittlement behavior. In our look this development is also explained by presence of the wavy element within the embrittlement mechanics. we have a tendency to suppose that the most issue moving steel abnormal embrittlement is quick nucleon intensity (dose rate or flux), flux impact manifestation depends on progressive fluence level. At low fluencies radiation degradation should exceed normative price, then approaches to normative that means and eventually became sub normative. information on radiation harm amendment together with through the ex-service RPVs taking into consideration chemical issue, quick nucleon fluence and flux were obtained and analyzed. In our opinion difference within the estimation on flux on radiation degradation impact is also explained by presence of the wavy element within the embrittlement mechanics. thus flux impact manifestation depends on fluence level. At low fluencies radiation degradation should exceed normative price, then approaches to normative that means and eventually became sub normative. what is more as a hypothesis we have a tendency to suppose that at some stages of irradiation broken metal need to be part renovated by irradiation i.e. nucleon bombardment. aborning throughout irradiation structure bear occurring once or sporadically transformation during a direction each degradation and recovery of the initial properties. consistent with our hypothesis at some stage(s) of metal structure degradation nucleon bombardment became ill issue. As a result oscillation arise that in larid cause increased information scatter.

Heat treatment when irradiation of reactor pressure vessel steels showed tempering of irradiation embrittlement. reckoning on the irradiation temperature, the embrittlement began to temper at ~220°C and was fully treated at 500°C with four h of tempering time.

The tempering behavior was ordinarily measured in terms of the Vickers hardness increase created by irradiation relative to the initial hardness as a operate of the tempering temperature. tempering results of different mechanical properties correspond to hardness results. throughout tempering, varied recovery mechanisms occur in several temperature ranges. These area unit characterised by activation energies from one.5 to 2.1 eV. The individual mechanisms were determined by {the different|the varied} time dependencies at various temperatures. The relative contributions of the mechanisms showed a nucleon fluence dependence, with the lower energy of activation mechanisms being predominant at low fluence and contrariwise. within the temperature vary wherever partial tempering of a mechanism transpire throughout irradiation, a rise in energy of activation was ascertained.

Trend curves for the rise in transition temperature with irradiation, for the relative increase of Vickers hardness and yield strength, and for the relative decrease of Charpy-V higher shelf energy area unit taken by the behavior of various mechanisms.

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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