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Prediction of Irradiation induced hardening by Artificial Neural Network for 304 and 316 stainless steels

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1. Introduction

The internal structures of pressurized water reactors (PWR) located close to the reactor core are used to support the fuel assemblies, to maintain the alignment between assemblies and the control bars and to canalize the primary water. In general these internal structures consist of baffle plates in a solution annealed (SA) 304 stainless steel and baffle bolts in a cold worked (CW) 316 stainless steel. These components undergo a large neutron flux at temperatures between 280 and 380°C. As a result, the materials exhibit a substantial increase in yield stress and a reduction in ductility which may deteriorate the performance of a reactor operation. For instance the observed cracks in bolts, usually attributed to irradiation assisted stress corrosion cracking (IASCC).

In this work, we tried to apply a artificial neural network (ANN) approach to a prediction of a IASCC of an austenitic stainless steels SA 304 and CW 316. We have predicted the yield stress in terms of a dislocation loops size and density. Besides, we compared experimental data with prediction data by an artificial neural network.

2. Prediction Model and Results

2.1 Artificial Neuron Network (ANN)

The ANN performs fundamentally like a human brain. The cell body in the human neuron receives incoming impulses via dendrites (receiver) by means of chemical processes. If the number of incoming impulses exceeds a certain threshold value the neuron discharges it off to other neurons through its synapses, which determines the impulse frequency to be fired off. Therefore, processing units or neurons of an ANN consist of three main components; synaptic weights connecting the nodes, the summation function within the node and the transfer function. Synaptic weights characterize themselves with their strength (value) which corresponds to the importance of the information coming from each neuron. In other words, the information is encoded in these strength-weights. The summation function is used to calculate a total input signal by multiplying their synaptic weights and summing up all the products.

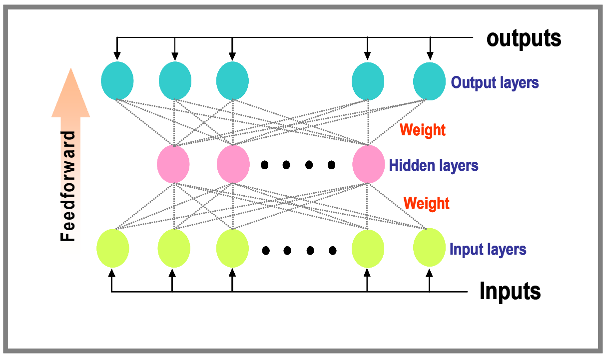

Figure 1. Scheme of Multi-Layer Perceptron (MLP).

2.2 Prediction Method

The artificial neural network code NeuroShell Predictor was used to analyze the data and two different training performances were investigated. (Fig. 1.)

· Input layers: temperature, dose, dislocation loop size, dislocation loop density.
· Output layers: yield strength
· Training strategy: genetic (combines a genetic algorithm with statistical estimator)

2.3. Evolution of the yield stress of the irradiated Materials

A measure of a irradiation hardening is the difference In a yield stress at 0.2% plastic strain between irradiated ($\sigma_{e,i}$) and unirradiated($\sigma_{e,ni}$) materials : $\Delta\sigma_e = \sigma_{e,i} - \sigma_{e,ni}$. The magnitude of the hardening depends on the irradiation damage dose, on the irradiation conditions (temperature, flux, spectrum . . .) and the initial state of the materials (chemistry, state of a deformation).

Table 1. The prediction of the dislocation loop size and density for an austenitic stainless steel SA 304 and CW 316.

Material	Temperature (°C)	Dose (dpa)	Dislocation loop size (nm)	Dislocation loop density (10^{22} m^{-3})
SA 304	360	1	5.30821	5.840002
		3	6.58899	6.400621
		5	8.01956	3.9247
		8	11.65091	3.081838
		10	12.23358	3.218955
		13	12.38342	3.294482
		15	12.38497	3.299244
		20	12.38504	3.300009
CW 316	360	1	5.30821	3.217652
		3	9.79457	3.217675
		5	11.91714	3.217697
		8	12.10407	3.217731
		10	12.10959	3.217753
		13	12.11351	3.217787
		15	12.11414	3.217809
		20	12.11437	3.217865

2.4 Predictions of yield strength

According to *G.S. Was* and *J.-P. Massoud* experimental data, the data for dislocation loop characteristics does not existed at 360°C. So, we predicted the dislocation loop size and density for an austenitic stainless steel at 360°C. The results of the prediction are listed in Table 1. Afterwords, we predicted the yield strength of SA304 and CW316. (Fig.2.)

The relative importance of the input variables are predicted by the neural network. In the case of SA 304 material, the loop size is significantly better than the others However, the predicted loop density of the CW 316 material is more important than the other input layers in the neural network.

These typical curves of irradiated austenitic steels are increased which leads to a large increase in the yield stress. The yield and ultimate tensile stress are almost the same. The ANN used here is to describe the irradiation induced hardening. The damage doses are higher than 10 dpa. This suggests that an irradiation hardening may not be saturated with a dose. This is in contradiction with experimental data; Fig. 2. clearly shows the saturation of the yield stress for doses beyond 10 dpa.

3. Conclusion

An artificial neural network was used to analysis a radiation damage. Neural networks have the ability to learn patterns and trends in datasets with several variables and can effectively use an interpolation to make predictions for cases where there are no data. Based on experimental data of a radiation damage from *G.S. Was* and *J.-P. Massoud*, we tried to apply the artificial neural network (ANN) approach to a prediction of a IASCC of stainless steels. Four input parameters for the neural network were the temperature, dose, loop size, loop density. Validation of the prediction had a good agreement with the experimental data.

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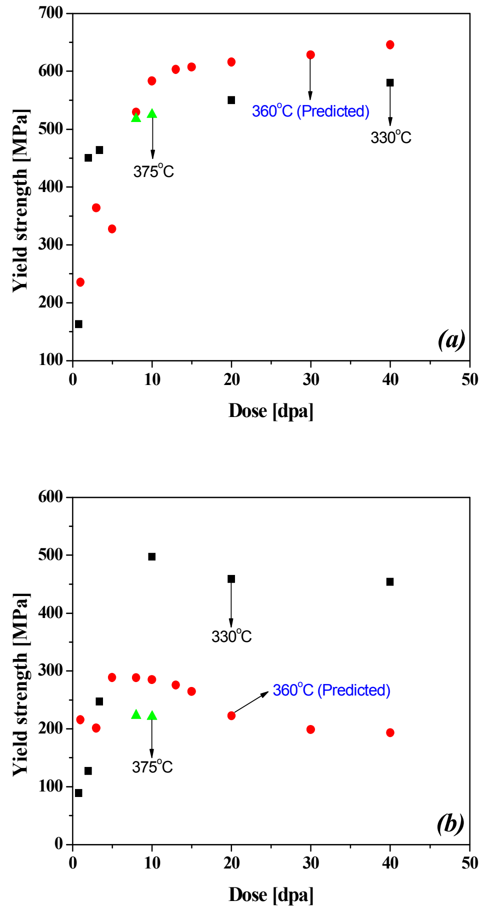

Fig. 2. Prediction of hardening for material (a) SA 304 and (b) CW 316.

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