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ANN Modeling of Nickel Base Super Alloys for Time Dependent Deformation

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***Abstract*—Alloys 617 and 276 are nickel-based super alloys with excellent mechanical properties, oxidation, creep-resistance, and phase stability at high temperatures. These alloys are used in complex and stochastic applications. Thus, it is difficult to predict their output characteristics mathematically. Therefore, the non-conventional methods for modeling become more effective. These two alloys have been subjected to time-dependent deformation at high temperatures under sustained loading of different values. The creep results have been used to develop the new models. Artificial neural network (ANN) was applied to predict the creep rate and the anelastic elongation for the two alloys. The neural network contains twenty hidden layer with feed forward back propagation hierarchical. The neural network has been designed with MATLAB Neural Network Toolbox. The results show a high correlation between the predicted and the observed results which indicates the validity of the models.**

***Index Terms*—Super alloys, Creep, Artificial Neural Network**

I. INTRODUCTION

Austenitic Alloys 617 and 276 have been identified as the suitable structural materials for heat exchanger application in the next generation nuclear plant (NGNP). The concept of Next Generation Nuclear Plant (NGNP) program had been introduced in parallel within the charter of USDOE and Generation IV International Forum (GEN IV) [1] to stand-in more efficient utilization of nuclear heat to generate electricity in the twenty-first century. NGNP program has been focused on the utilization of a very high-temperature gas-cooled reactor (VHTR) concept involving a modular high-temperature gas-cooled reactor, using helium as a coolant and a closed-cycle gas turbine to generate power, in contrast to steam-based turbine used during the 1970s and 1980s. In the VHTR concept, the helium from a reactor core was planned to drive the turbine directly or indirectly by heating air or nitrogen that would drive the turbines. The reactor core outlet temperature or the turbine inlet temperature had been recommended to be in the vicinity of 950^{0}C at pressures up to 7 MPa for a design life of 60 years [1]. Since the design life is long, the time dependent deformation characteristics are demanded for both the alloys.

Alloy 617 is known to possess excellent resistance to creep deformation and stress rupture properties at temperatures up to 850^{0}C [2], [3]. Further, both alloy 617 and 276 can maintain excellent metallurgical stability and corrosion resistance even after its prolonged exposure at elevated temperatures [4]. Extensive experimental work was performed and published by the University of Navada Las Vegas (UNLV) researchers relevant to several nickel base super alloys [5], [6]. Numerical results and comparisons with experimental data for the creep deformation of the single crystal superalloy LEK94 is discussed by Trinh and Hackl [7]. Hierarchical Multiscale Modeling of Ni-base Superalloys for creep deformation at elevated temperature is proposed by Jin E. Song [8]. In this research a new models have been developed for modeling the creep rate and the anelastic elongation for the two alloys: 617 and 276.

II. RESEARCH METHODOLOGY

A. Creep Test Materials

The experimental heat of Alloy 617 was custom-melted at the Huntington Alloys Corporation, West Virginia using a vacuum-induction-melting (VIM) practice. This VIM heat was subsequently processed into rectangular and round bars of different dimensions using forging and hot-rolling. The hot-rolled rectangular bars were subsequently subjected to cold-rolling operation to reduce their thickness. Since both round and rectangular bars had substantial residual stresses resulting from cold and hot-rolling operations, these processed materials were thermally treated to relieve these internal stresses. This thermal treatment consisted of solution-annealing at 2150 ℉ (1175 ℃) for variable time periods depending on the thickness of the processed bars. Such thermal

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treatment is known to produce large-sized austenitic grains with annealing twins in Ni-based alloys. The strengthening of Alloy 617 is known to be the result of precipitation of metal carbonitrides M(C, N) and $M_{23}C_6$ carbides within the matrix of this alloy [9]. On the other hand Alloy 276 was procured from two different vendors in properly heat-treated conditions. This heat treatment included solution-annealing at 2050 ℉ (1121 ℃) followed by rapid cooling, thus providing a fully austenitic microstructure.

B. Creep Test Specimens

For creep testing, smooth cylindrical specimens having an overall length of 4-inches (101.6 mm) and a gage length of 1.48-inches (37.59 mm) were used. A ratio of 6:1 was maintained between the gage length and diameter. The test specimens were fabricated in such a way that the gage section was parallel to the longitudinal rolling direction. Specimens were machined according to the size requirements prescribed by the ASTM Designation E 139-2000 [10]. Circular grooves were machined at both ends beyond the shoulder region of the specimens to attach dual extensometers for monitoring elongation during creep testing.

C. Experimental Test Procedure

Creep is a time-dependent enelastic deformation of a material at a constant load / stress [11]. To generate a creep curve, a constant load is applied to a cylindrical specimen at a constant temperature, and the resultant strain is recorded as a function of time. Creep testing of Alloy 617 and 276 were performed at temperatures of 750 and 850 ℃ according to ASTM Designation E 139-2000 [10]. The selection of the testing temperatures was based on an understanding that meaningful creep data could be generated at a homologous temperature (ratio of test temperature, T to melting temperature, Tm) of greater than or equal to 0.5 [11]. Four K-type thermocouples were used to monitor the testing temperature inside the furnace. Three thermocouples were firmly attached to the test specimen at the top, middle and bottom portion, respectively. A ‘Windows Computer Creep System’ (WINCCS) software was used to simultaneously monitor and record the instantaneous temperature at the top, middle and bottom location of the test specimen. The elongation at the gage section of the test specimen was measured by using two extensometers. The average elongation measured by the left and right extensometer was used to analyze the creep data. Creep testing was performed for a maximum period of 1000 hours at constant applied loads equivalent to 10 and 25 % of the yield strength (YS) values of Alloy 617 and Alloy 276 at their respective testing temperature.

III. ANN APPLICATION

The recent developments of modeling concern the use of artificial intelligence. Neural network (NN) present one of the techniques in computerizing the human thought processes [12]. It is a technique that makes a computer simulates the behavior of human brain neurons. The neural network model is constructed by using a set of data consisting of input and output variables. In the training process, the structure of the model is self adjusted to the data, and the final model can be used for predictions [13]. The NN then approximates the functional relationship between the attribute values and the response during the training. Once trained, the attribute values of a process under development are supplied to the network, which applies the approximated function obtained from the training data and computes a prospective response [14].

The recent developments of predicting models concern the use of artificial intelligence such as neural network and fuzzy logic. The neural network technique is a method that makes a computer simulates the behavior of human brain neurons by using a set of data consisting of input and output variables. In the training process, the structure of the model is self-adjusted to the data, and the final model can be used for predictions [13].

The training algorithm is defined as a procedure that consists of adjusting the weights and biases of a network that minimize selected function of the error between the actual and desired outputs [15]. The process of training a neural network can be broadly classified into two typical categories: supervised learning and unsupervised learning. Back-propagation is one of the supervised learning.

In this research three input factors have been used for modeling the creep rate and anelastic elongation for the alloys 617 and 276. Fig. 1 shows the NN structure.

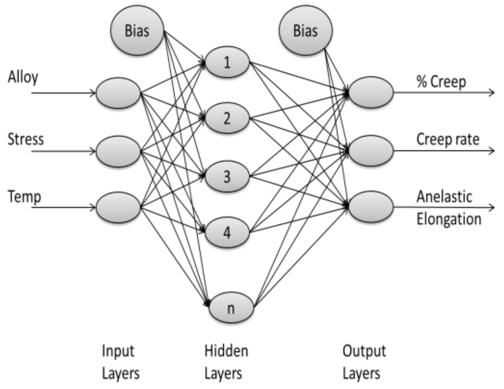


Figure 1. NN structure

The neural networks pass the output of their layers through activation functions. These activation functions scale the output of the neural network into proper ranges. The default choice for the feed forward Layer is the sigmoid activation function as in (1).

$$f(x) = \frac{1}{1+e^{-x}} \tag{1}$$

Twenty samples have been used to train the neural network and to adjust the weights and the biases of each unit in order to reduce the error between the desired output and the actual output. The twenty samples have been duplicated to get high accurate results. The NFTOOL box in the MATLAB has been used. The back propagation algorithm applied to determine the layer's weights. Table I concluded the architecture, learning system, specifications of the neural network model used in the development of the new model.

TABLE I. MODELING BY USING NEURAL NETWORK

Tool	**MATLAB**
Tool box	Nftool
Architecture	Feed forward
Learning system	Supervised learning
Algorithm	Back propagation Levenberg-Marquardt algorithm (LM)
Activation Function	Sigmoid (logistic function)
Number of layers	3 layers (input, hidden and output)
Data ratio	70:15:15
Number of hidden layers	20

Fig. 2 shows the neural network structure that generated by the software. Four inputs, twenty hidden layers, six output layers and six inputs.

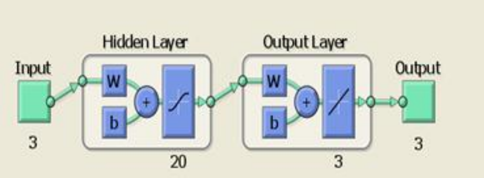
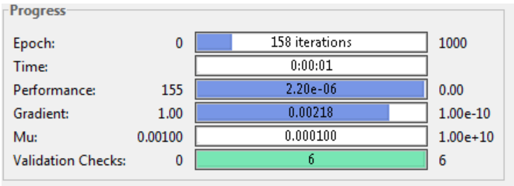


Figure 2. Neural network structures

The progress shows the final results given after 158 iterations with 1 second as shown in Fig. 3.



Progress

Epoch:	0	158 iterations	1000
Time:		0:00:01	
Performance:	155	2.20e-06	0.00
Gradient:	1.00	0.00218	1.00e-10
Mu:	0.00100	0.000100	1.00e+10
Validation Checks:	0	6	6

Figure 3. NN progress

The best Validation was 4.352e^{-6} at iteration 152 as shown in Fig. 4.

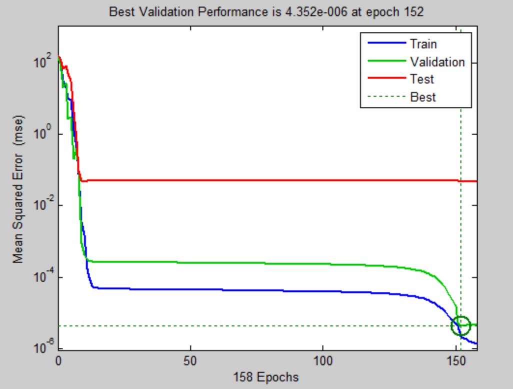


Figure 4. Validating performance

The regression plot for training the model is summarized in Fig. 5. The plots display the network outputs with respect to targets for training. For a perfect fit, the data should fall along a 45 degree line, where the network outputs are equal to the targets. For this study, the fit is very good for all data sets, with R values was of 0.99.

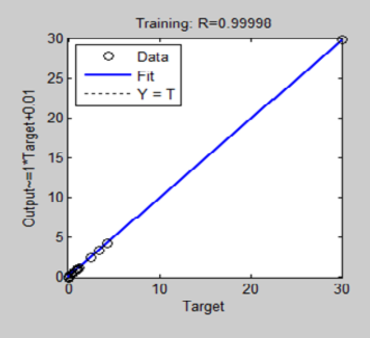


Figure 5. Plot of data training regression

The regression plot for validation the models are summarized in Fig. 6. The plot displays the network outputs with respect to targets for validation. For this study, the fit is very good for all data sets, with R values was of 0.98.

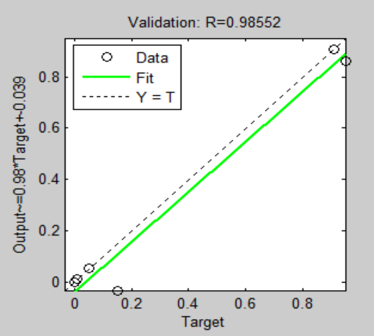


Figure 6. Plot of data validation regression

IV. VALIDATION

A comparision of the measured and the predicted values to determine the deviation between the theoretical and actual value that comes out from ANN statistical regression models have been conducted. Fig. 7 shows the average deviation between the actual and the predicted values by the neural network models.

The results show different percentage of accuracy. However, all the results show that all the models are valid.

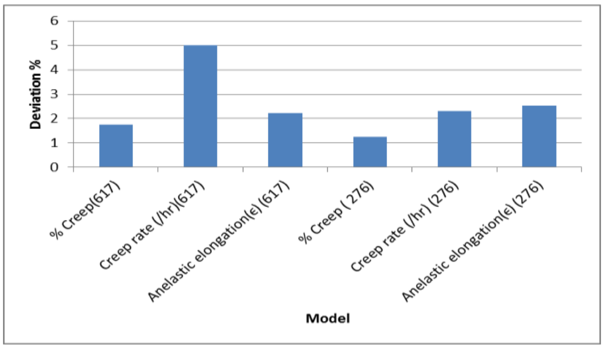


Figure 7. Models accuracy

V. CONCLUSIONS

In this work, the creep rate and the anelastic elongation for two super alloys; 276 and 617 have been investigated.

The influence of temperature and the stress on the creep rate and the anelastic elongation have been modeled. The neural network as of the important unconventional tools has been used to develop new models. These models showed different levels of accuracy. The results show different percentage of accuracy. However, all the results show that all the models are valid.

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