

# A BACK PROPAGATION MÓDSZER ALKALMAZÁSA A GTN PARAMÉTEREK MEGHATÁROZÁSÁBAN

## THE APPLICATION OF BACK PROPAGATION APPROACH IN THE DETERMINATION OF GTN PARAMETERS

CHAHBOUB Yassine\*, Dr. SZAVAI Szabolcs\*\*

### ABSTRACT

*The Gurson–Tvergaard–Needleman (GTN) model, is a powerful approach that we use to anticipate the failure of pipelines based on lab samples, To find GTN parameters straightforwardly we need to consume much time. The immediate strategy to find the GTN parameters and anticipate the damage of the materials is finding the right mix between the experimental and Finite Element results.*

*In this paper, we had the option to discover the GTN parameters for the single edge notched tension (SENT) specimen dependent on the Notch specimen test in a brief timeframe by utilizing the backpropagation approach. The outcomes that we got from this work demonstrate that we can utilize the backpropagation concept as another alternative to determine the GTN parameters and predict the failure of materials.*

### 1. INTRODUCTION

Guaranteeing that the Nuclear plants work perfectly, means that we need to guarantee that all the parts are well maintained and in decent condition; moreover one of these parts is the pipeline, the spillage issue in the pipelines is one of the primary basic issues that may influence the function of the Nuclear Power Plant, and the ferritic steel is the fundamental kind of material from which the pipelines are built.

The GTN model is an incredible micromechanical model that is utilized in the industry, to foresee the commencement and engendering of the crack, the GTN model is implemented in FEM programming tools as MSC Marc Mentat.

The direct process to find the GTN parameters is the mix between the test and Finite Element Modeling results, but its time consuming [1], so to determine the GTN parameters in a brief timeframe and with great exactness, we will utilize the combination of the backpropagation, Finite Element Modeling and experiment results.

#### 1.1. GTN model

The GTN model was chosen in this research for its simplicity and recognition in the industry field many studies [2]; [3]; [4]; prove that the model is successfully used to describe the ductile deformation behavior of the material with accurate results.

- The GTN model is implemented in MSC MARC Mentat Finite element modeling software and provides the possibility to determine GTN parameters without taking into account the void nucleation parameters. However, no literature was found on the issue related to the time consumed to implement the GTN model and to predict the failure of materials.
- GTN model and its extension have been applied for various industry fields such as Nuclear, Aerospace.
- The implementation of the GTN model requires the determination of different material parameters, and simulation procedures are required.
- The successful implementation of the GTN model during the design phase would be beneficial to the nuclear industry to get more specific and accurate data about material behavior during its service life, and the conditions that might lead to the material failure, which for instance help to boost the final product quality and ensure long time service operation without failure.

The mathematical form of the GTN model can be presented as below :

$$\phi = \frac{\sigma_e^2}{\sigma_M^2} + 2q_1 f^* \cosh \left[ \frac{tr\sigma}{2\sigma_M} \right] - (1 + q_1^2 f^{*2})$$

In which  $\phi$  is the Gurson plastic potential,  $q_1$  is the material constant,  $tr\sigma$  is the sum of principal stresses,  $\sigma_M$  is the equivalent flow stress,  $\sigma_e$  is the effective stress. Furthermore,  $f^*$  is the ratio of voids effective volume, more details about the model can be found in [2].

To use the GTN model, we have to determine six parameters.

$f_0$  =Initial void volume fraction

$f_n$  =the new voids nucleation

$f_c$  =the voids volume ratio at the beginning of nucleation

$f_f$  =is the voids volume ratio when a fracture occurs

$S_N$  =the voids nucleation mean quantity

$\epsilon_n$  =strain at the time of voids nucleation

\* PhD Student University of Miskolc

\*\* Assistant Professor, University of Miskolc

The determination of those parameters it's not an easy task, and it takes a long duration to find the correct set of parameters that could predict the failure of pipes. Few researchers could give initial values of GTN parameters [5]; [6]; [7]; [8]; as listed in Table 1 [1].

Table 1 Gurson parameters according to literature

Reference	$E_N$	$S_N$	$f_0$	$f_c$	$f_n$	$f_f$
Bauvine au et al. (1996)	-	-	0.002	0.004	-	-
Decamp et al. (1997)	-	-	0.002 3	0.004	-	0.22 5
Schmitt et al. (1997)	0.3	0.1	0	0.06	0.002	0.21 2
Skallerud and Zhang. (1997)	0.3	0.1	0.000 3	0.026	0.006	0.15
Bensedd iq and Imad. (2008)	0.3	0.1	0	0.004 -0.06	0.002 -0.02	~0.2

## 2. METHODS AND RESULTS

The prediction of failure of SENT specimen is done by following the steps below:

- Perform the small scale tests (SENT, NT) To provide the Experimental data.
- Make the Finite Element Simulations to make the database use the backpropagation approach.
- Determination of the GTN parameters by using backpropagation.

### 2.1. NT sample simulation

To find the GTN parameters for the SENT sample (figure 1), we decided to use the notch tensile test (figure 2) results as a database to train our Neural network.



Figure 1 QUARTER OF THE SENT specimen

By applying the symmetry we make a 2D FEM model just for the quarter of the NT specimen (figure 2).

The mesh size has to be very fine near to the crack tip, and its the most sensitive place in the sample, unlike the upper part of the specimen, which saves a little more computing time the mesh size in the front of the pre-crack tip is  $0.125 \text{ mm} \times 0.0625 \text{ mm}$  and the mesh is composed of quadratic axisymmetric elements with 8 nodes.

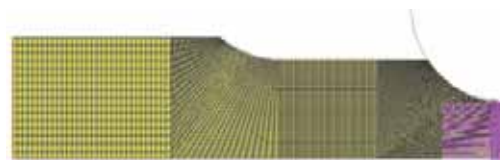


Figure 2 NT specimen

### 2.1.1 ANN AND DATABASE CREATION

To provide the database necessary to apply the artificial neural network (ANN) approach, eighty simulations were needed for an NT specimen with a different set of GTN parameters.

Backpropagation is among the most popular and forms of artificial neural networks and can deal with non-linear models with high accuracy.

the backpropagation procedure consists of finding the parameters which minimize the difference between a predicted response by the finite element method and the experimental one. The main drawback of this approach is its prohibitive time consuming especially when more than one test is used. [1]

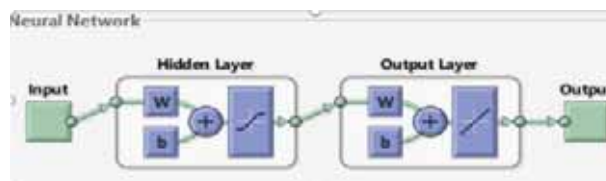


Figure 3 Neural Network architecture

The backpropagation algorithm has been one of the most widely used machine learning algorithms. The gradient of the loss function is calculated by backpropagation concerning the weights of the network. The backpropagation computes gradient by applying chain rule computing gradient one layer at a time starting from the last layer and propagate towards input which is the opposite to the forward feed propagation approach. [9]

The neural network is usually composed of three layers, namely, the input layer, hidden layer, and output layer. For the hidden layer, each neuron receives total outputs from all of the neurons in the input layer.

For the NT test, the trained model consists of one hundred neurons in the input layer (figure 3), eighty neurons in the hidden layer, and six neurons in the output layer (100-80-6).

The neurons of the input layer represent the values of the reaction force  $F$  of the NT specimen after simulations, and the neurons of the output layer are the eighty sets of the GTN parameters.

After training the Neural Network as described above, we could determine the six parameters for SENT specimen by using the ANN already trained, but in this time the

input data would be the experimental results of the SENT specimen and the output data are the predicted GTN parameters, the process didn't take a lot of time, it around 3 to 5 minutes then the ANN predicts the GTN parameters.

The GTN parameters determined by using the ANN are  $f_0=0.0001$ ,  $f_c=0.0042$ ,  $f_r=0.21$ ,  $S_n=0.034$ ,  $\epsilon_n=0.34$ ,  $f_n=0.085$ .

The GTN parameters found in this study are related to our SENT specimen and it cannot be compared to the Literature (Table 1) as the conditions of the experiments are different and also the type of materials.

## 2.2 Prediction of Crack propagation for SENT SPECIMEN

To check the validity of the GTN parameters that we found from training the database provided from NT simulations, We are going to predict the failure of the SENT specimen (figure 1).

As we did for the NT simulation, we are going to use the axisymmetry, and make the 3D model just for the quarter of the specimen, the FEM model contains a total of 75,461 nodes and 68,160 elements. The mesh size in front of the pre-crack tip is the same as the NT specimen to avoid the mesh sensitivity effects.

After making just one simulation with the GTN parameters that we got from using the backpropagation approach, the results (figure 4) show that the simulation results of the SENT specimen fits the experimental curve and they are in good agreement, which proves that the GTN model was a great tool to predict failure of SENT specimen, during our simulation, the maximum reaction force found was 45 kN, which almost the same value found during the experiment.

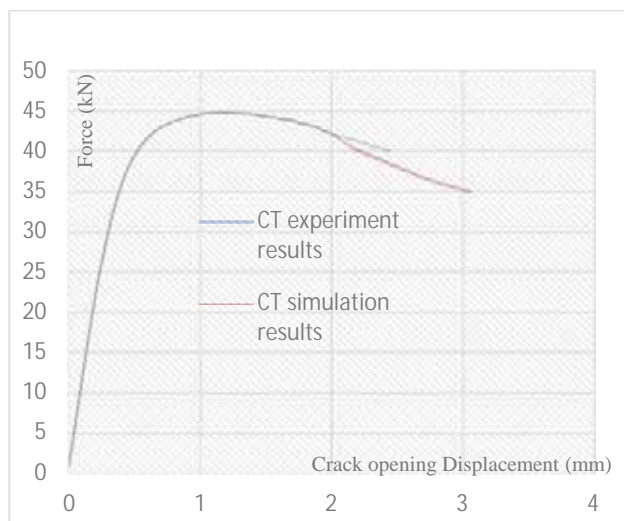


Figure 4 backpropagation and experiment results in fitting curves

## 3. CONCLUSION

The determination of the correct set of GTN parameters cannot be done in a short time, especially if we want to predict the failure of materials such as pipelines, for this reason, the usage of an approach such as backpropagation, will be an alternative to find an accurate set of GTN parameters.

To close, the backpropagation approach will help us to find a solution to some problems such as transferability, which means we can save a lot of money with the direct prediction of failure of huge material from small lab specimen in a short time.

## 4. REFERENCES

- [1] Y., Chahboub; Szávai, Szabolcs; H., Aguir *Determination of GTN parameters using artificial neural network for ductile failure* In Szita Tóthné, Klára; Jármay, Károly; Voith, Katalin (eds.) *Solutions for Sustainable Development: Proceedings of the 1st International Conference on Engineering Solutions for Sustainable Development, (ICSSD 2019)* London, the United Kingdom / England: CRC Press, (2019) pp. 25-32. , 8 p.)
- [2] S. Acharyya, S. Dhar 2008 *A complete GTN model for prediction of ductile failure of pipe* *Journal of Materials Science* 43(6):1897-1909
- [3] Sharlotte L. B. Kramer, et al 2019 *The third Sandia Fracture Challenge: predictions of ductile fracture in additively manufactured metal* *International Journal of Fracture*
- [4] Y.chahboub, S.Szabolcs, 2019 *Determination of GTN parameters for SENT specimen during ductile fracture* *Procedia Structural Integrity* Volume 16, 2019, Pages 81-88
- [5] Bauvineau, L., Burlet, H., Eripret, C., & Pineau, A.L., 1996. *Modeling ductile stable crack growth in a C-Mn steel with local approaches*. *Journal de Physique IV – Proceedings 06 (C6)*, C6-33–C6-42.
- [6] Benseddiq, N., Imad, A., 2008. *A ductile fracture analysis using a local damage model*. *International Journal of Pressure Vessels and Piping* 85 (4), 219–227.
- [7] Decamp, K., Bauvineau, L., Besson, J., Pineau, A., 1997. *Size and geometry effects on ductile rupture of notched bars in a C-Mn steel: experiments and modeling*. *International Journal of Fracture* 88 (1), 1–18
- [8] Skallerud, B., Zhang, Z.L., 1997. *A 3D numerical study of ductile tearing and fatigue crack growth under nominal cyclic plasticity*. *International Journal of Solids and Structures* 34 (24), 3141–3161.
- [9] R. Allavikutty, S. Chukka, R.Jayaganthan 2020 *Prediction of Fatigue Crack Growth Behaviour in Ultrafine Grained Al 2014 Alloy Using Machine Learning* *Open Access Metallurgy Journal*