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Methodology of the mechanical properties prediction for the metallurgical products from the engineering steels using the Artificial Intelligence methods

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Abstract: The paper presents the new method for forecasting the yield point and the ultimate tensile strength for steel. These parameters are calculated basing on the chemical composition and technological factors of steel manufacturing. The artificial neural network technology was used for development of models making prediction of these properties possible. Software was developed, basing on these models, searching for the optimum chemical composition of steel, so that – at the particular conditions of the technological process – the risk of manufacturing the products that would not meet the requirements of the pertinent standards would be minimised. Search for the optimum chemical composition makes use of the genetic algorithms.

Keywords: Ultimate Tensile Strength, yield point, artificial neural networks, genetic algorithms, Artificial Intelligence

1. INTRODUCTION

The main goal of the research work was to develop two models which would make it possible to predict the UTS and yield point values of the investigated steel products [1,2,3]. The artificial neural networks technology was employed for developing the models. Very good results which are obtained from simulations made with them result from the solid theoretical background on which they are based [4-6,8,10]. The neural networks – after their training phase - have the significant capability to generalise the simulated phenomena to case which were not included in the training set. This neural networks' property gives them their biggest advantage over the analytical methods, making it possible to forecast the investigated phenomenon at the practically arbitrary set of the input parameters.

2. EXPERIMENTAL DATA

About 50000 steel laboratory test results were acquired before commencing the investigations. The investigations were made using the test results collected in the big steel plant over four years. Five steel grades were selected for this paper after some statistical analyses: S235JR, S235JRG2, S235JRG3, S275JR, S355G1S [11]. The following products are made, among others, from these steels: I-bars, channels, and other commonly used steel

products. These results were used as the training set for the developed models. Many network tyes were tested during development of models, like: linear networks, RBF networks with the radial base functions, triple and quadruple layer networks [10], in various configurations. These tests made it possible to choose the optimum models that calculated the simulated properties best. The network evaluation was made basing on the following parameters: quality of the subsets, errors of the subsets, standard deviations of errors, average error, quotient of standard deviations, and Pearsson's R correlation. The quadruple layer networks proved to be best in both cases (with two hidden layers).

The next research stage consisted in development of tools allowing such modifications of the network input parameters so that the matching of the calculated values with the results searched for would be the best. Genetic algorithms (GA) were used to solve this task [5,7,9]. Employment of the genetic algorithms makes it possible to attain very good results and finding the non-standard solutions for the problem in question.

3. MTERIAL DATA ANALYSIS PROCEDURE

A set of about 13000 laboratory test results carried out on products made from the previously selected steels was used as the training set (input data) in the investigations described in the paper [10]. These results included: examinations of the chemical composition of steel (aluminium, sulphur, arsenic, silicon, carbon, tin, chromium, titanium, copper, vanadium, hydrogen, manganese, molybdenum, nitrogen, niobium, nickel, phosphorus), information about the technological process properties, like rolling reduction ratio, product manufacturing dates, cross section areas of the stock material and final products, and UTS and YP test results, along with the dimensions of the test pieces.

Many network and training algorithm combinations were tested within the framework of the research. The multilayer networks were selected for further research (with two hidden layers): UTS MLP 24-20-5-1, YP MLP 24-18-5-1, as yielding the best results. The detailed description of the network results after the completed training process is presented in the table.

3.1. Software implementation of the material data processing system

The system was developed, basing on the models, making it possible the efficient management of the calculated results. The system consists of the four main modules (Figure 1):

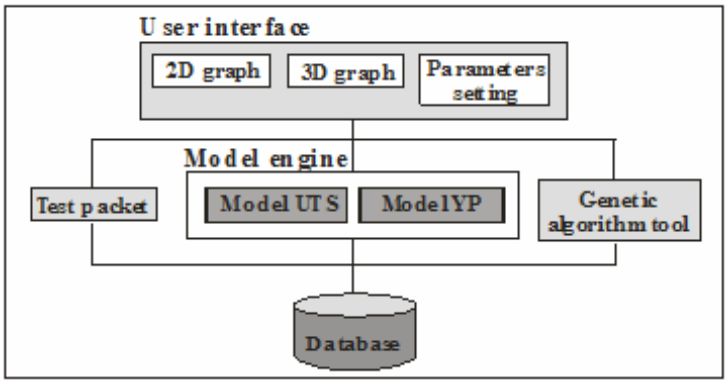

Figure 1. Schematic diagram of the models management system

Results calculated by the models were used for many analyses of steel properties for various combinations of the input parameters. Exemplary results are shown in Figure 2.

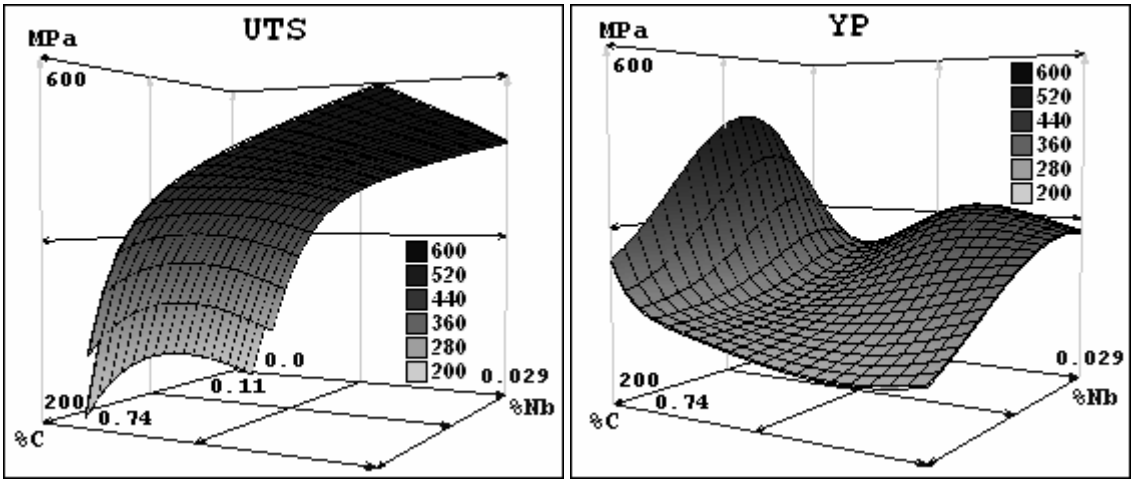

Figure 2. Exemplary results of the calculated UTS and YP values versus concentrations of niobium and carbon

3.2. Automation of the input parameters selection for the required steel properties

The tool for automatic optimisation of the input parameters to attain the required parameters of steel was developed after working out the models. The genetic algorithms technology was employed for searching the required properties. The average absolute difference between the results calculated by the network for the specified parameter and the specified reference standard was used as the match (target) function.

Two examples are shown below (Figure 3) of employing this tool for searching the solution for a pair of reference standards. The reference standards were defined for variability of carbon concentration in steel.

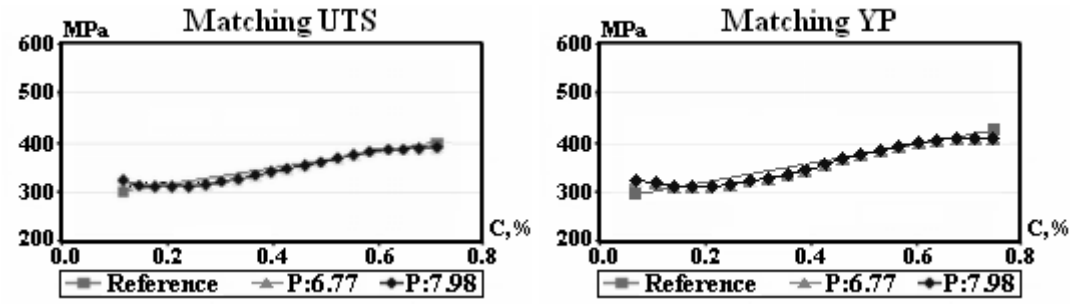

Figure 3. Plots of the first simulation of matching UTS and YP to reference standard No 1* with the variable carbon concentration. Plots show two exemplary solutions (Table 10).

* reference standards used: UTS 400-500 MPa with the carbon concentration variability 0.11-0.71%, YP 300-400 MPa with the carbon concentration variability 0.11-0.71%

Changes of the following parameters were locked during the simulation: 3, height: 100 mm, thickness: 12 mm, width: 25 mm, hydrogen: 0, stock cross section area: 1120 mm^2, product cross section area: 114 mm^2, elongation coefficient: 1.175.

4. SUMMARY

The developed system is a handy research tool making it possible to carry out computer simulations, suitable for forecasting the yield point and ultimate tensile strength values versus chemical composition of the steel and its technological process features. The system software makes smooth change of the input parameters possible as well as the simultaneous observation of their effect on the calculated parameters' values. These values are presented in the form of plots versus the selected input parameter in the 2D plots or two parameters in the 3D ones. This solution makes quick searching possible of the hyper-surfaces created by the YP and UTS properties to determine the critical correlations of the input parameters in terms of the calculated properties, and also for finding the optimum selection of the input parameters for the required properties. The auxiliary tool for selection of the chemical composition and the technological issues, operating basing on the genetic algorithms makes automatisation possible of the selection process of these parameters. The result of the tool operation is the set of the input parameters vectors, for which the calculated values of the object function are minimum, i.e., representing the specified reference standard in the best way.

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