THE APPLICATION OF ARTIFICIAL NEURAL NETWORKS AND EVOLUTIONARY ALGORITHM FOR THE DESIGNING OF GAS NITRIDING PROCESS

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***Abstract**: The authors have undertaken a research task with a view to apply of evolutionary algorithms and artificial neural network to design of the course of a gas nitriding process, which guarantees to obtain the expected hardness profile in the nitrided layer. The gas nitriding process is widely used in industry in order to improve the functional properties of machine and tool parts. First of all, the artificial neural network was trained dependences between physical properties of steel and process parameters in relation to hardness profile, formed in gas nitriding process. Those data was collected experimentally. Such trained neural network was used as a mathematical model for the design approach of gas nitriding process. The aim of such designing was to predict the parameters of nitrinding industrial process, in which the required hardness profile of nitriding layer will be obtained. Prediction of manufactory conditions was realized with the help of evolutionary algorithms. In the approach developed, each chromosome includes encoded parameters of a single steel nitriding process. For each chromosome, a steel hardness profile related to it is determined by the model which is represented by neural network. On the further step, the chromosomes undergo a selection, a modification with the aid of crossing mutation operations and promotion to the next population. In this manner, by approach of a directed evolution of steel nitriding parameters, one is selected for which the hardness profile matches the best to profile sought.*

***Keywords**: evolutionary algorithm, neural network, designing of nitriding process, nitriding layer, hardness profile, model, manufactory conditions prediction.*

***ACM Classification Keywords**: D.2.2 Design Tools and Techniques - Evolutionary prototyping*

Introduction

Computer aided designing of formation technologies of surface layers with the required and repeatable functional properties constitute one of the key issues of the surface layer engineering. The gas nitriding process is known for a long time as great support for improving of durability of industrial tools such as cog-wheels or cutting tools. The layer developed during steel gas nitriding is composed of the surface zone of iron (carbon) nitrides and the diffusive zone located directly below [Somers 1995, Rozendaal 1985, Lengenhan 1992, Zyśk 1979]. The zone of (carbon) nitrides for pure iron, created at a relatively high value of nitric potential is composed, in compliance with Lehrer's diagram [Somers 1995, Rozentaal 1985]. It was assumed that his growth kinetics of the diffusive layer depends of the process temperature only. In the case of alloy and carbon steels, the sequence of phases in the zone of (carbon) nitrides changes in the duration of the process [Lenagenhan 1992, Zyśk 1979, Schewerdtfeger 1969, Lehrer 1930, Somers 1990, 1997, Mittemeijer 1980, 1983]. On the basis of the research in papers [Ratajski 2003, 2009, Malinov 2003], it was demonstrated that owing to the construction and phase composition of the iron (carbon) nitride zone being different than in the case of iron, as well as the structural changes occurring in that zone during the process, the quasi-equilibrium of nitrogen concentration is upset on the interfacial boundary of the diffusive zone/iron (carbon) nitride zone. Moreover, it was demonstrated that the phase structure of the iron (carbon) nitride zone has a significant contribution, regardless of the nitrogen potential and the temperature, to the creation of the diffusive zone, and its effective thicknesses g400, g500 and g600 in particular (Figure 1).

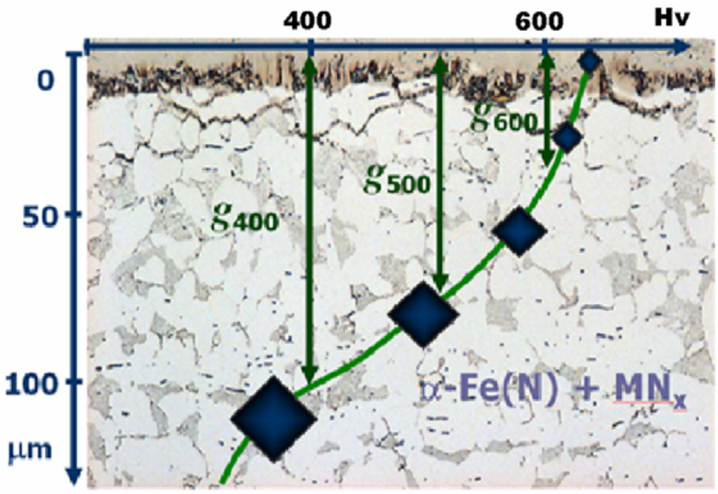

Figure 1. The effective thicknesses zone on the micro-hardness profile of nitride layer

To produce of the nitride layer is a very complex assignment therefore there is no derived accurate formula of mathematical model of such process so far. Difficulty of modelling came down from many very important parameters such as: chemical composition of steel (physical properties), process temperature which may not be constant during the process, nitrogen potential (K_N) [Ratajski, 2009] as well as method's recurrence. Designing of software for the system control of the gas nitiding process that could guarantee obtaining a layer with the required and repeatable functional properties is made difficult in connection with the phenomena and mechanisms which have an impact on the growth of the nitrided layer. As a result, there is an increasing interest in computer aided designing of surface layer formation technologies. The authors undertake attempt to design a software for prediction and control the gas nitride process. Such software is based on a artificial neural network which is used as a mathematical model for the evolutionary algorithm to solve of the inverse problem that mean to predict the determined process parameters based upon a required hardness profile. This is wary important for the industry because very often companies want to increase the endurance of tool to diamond level. In many cases the working environmental' process parameters are trying to get experimentally.

ANN as a model of a gas nitriding process

The mathematical model for determination of goal function for evolutionary algorithm is replaced by artificial neural network. Such ANN is trained with the help of data set which were collected experimentally. For the specified type of steel the sequence of gas nitridig process with different value of process parameters ware realized and the hardness profiles ware measured. Those data was used as a trainee set for the ANN as it is shown on figure 2. The implementation of such a concept for a specific surface treatment process enables to replace a very costly trial-and-error method, which is used at present in practice. However, it requires that a number of complex scientific and application problems be solved concerning modeling of confounded functional dependences between the surface layer properties and the characteristics of the process environment and the base material. The examples of process parameters and related hardness profile measured on chosen depth are shown in table 1. For same cases the process was repeated with different temperatures, duration of process or nitrogen potential and just after that the hardness profile was measured. For cases the nitriding process is repeated the hardness of surface layer is significantly greater than in the one stage approach.

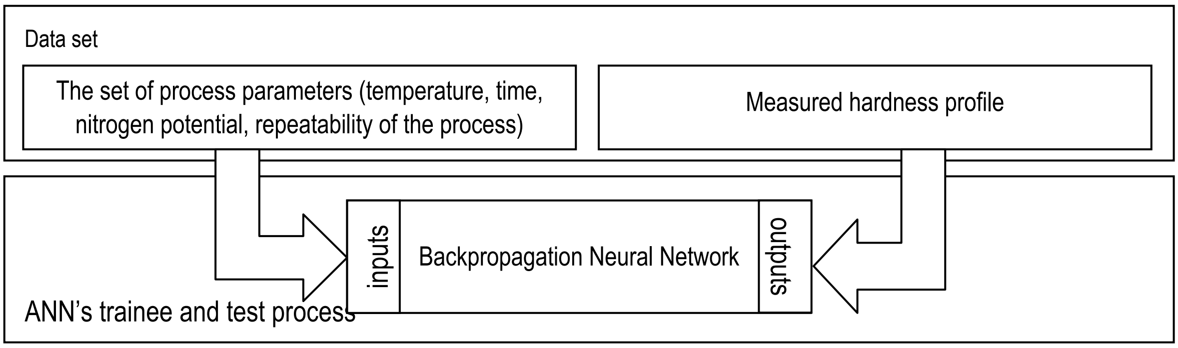

Figure 2. The schema of hardness profile determination with the help of ANN

For the experiment authors used a standard babckpropagation neural network with modified Chain's and Felside's trainee algorithm [Nałęcz 2000, Suszyński 2006, Kosikowski 2007]. The decision to choose such type of ANN was determined by its properties which are easy implementation of trainee algorithm, convergence and low duration of trainee process. Backpropagation ANN's require data to be coded in (-1;1) or (0 ;1) range which is imperfection of such networks, but they have very good approximation properties.

Table 1. Measured hardness profile received during gas nitriding process with related environmental parameters

Nr	Gas nitriding process parameters						Hardness profile [Hv] measured in chosen depth [um]							
	first stage			second stage										
	T_1[°C]	K_N	t_1 [min]	T_2[°C]	K_N	t_2 [min]	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**600**
1	530	6	120	-	-	-	660	600	360	310	290	280	260	260
2	530	6	720	-	-	-	695	680	610	530	460	385	335	280
3	570	3.2	240	-	-	-	655	600	505	415	335	295	270	250
4	570	3	480	-	-	-	715	630	550	475	420	375	340	270
5	570	3	960	-	-	-	740	680	625	575	525	470	415	280
6	550	3.5	720	-	-	-	620	605	525	425	365	320	300	270
7	550	30	720	-	-	-	690	655	600	530	465	395	365	280
8	570	5.2	1200	-	-	-	700	640	585	545	520	490	455	315
9	580	2	180	-	-	-	675	585	495	410	360	325	295	270
10	580	10.2	120	580	0.4	240	690	610	535	460	385	325	395	260
11	530	8.5	240	530	0.6	120	780	710	570	420	360	320	305	280
12	530	9	240	530	0.6	240	770	730	640	600	515	465	435	270
13	530	10	240	530	0.6	480	780	725	620	525	430	380	345	280
14	490	12	120	560	2.4	30	540	325	260	260	260	260	260	260
15	480	17	225	560	3.7	25	720	440	330	295	290	270	270	270
...														
85	490	10	180	570	2	180	715	640	480	400	355	315	225	250
...														

Evolutionary algorithm combined with ANN

To predict the nitriding process parameters based on exact hardness profile, that mean to solve the inverse problem, the evolutionary algorithm was used. In such approach each chromosome was defined by encoded parameters of a single steel nitriding process. For the experiment authors used tools made from the alloyed carbon steel known as 18HGT. Chromosomes sets form the so-called population. For each chromosome, a steel hardness profile corresponding to it is determined (Figure 3.). For this purpose, the earlier trained neural network is used, which performs the role of a model. If the end-point condition of algorithm is reached the demand parameters became predicted. In the opposite, each chromosome (a set of parameters) evaluates. The chromosomes undergo a selection (a selection of chromosomes with the best matching), and a modification with the aid of crossing over and mutation operations. The chromosome selection algorithm was a nonlinear ranking with stress (pressure) coefficient equal to 0.3. The mutation treatment of individuals in population was assigned by standard single one-point crossing with randomly calculated probability which was less than 0.8. At the end of population evolution step, the homogeneous individual, with constant probability equal to 0.2, mutation was conduct. In such approach, by way of a directed evolution of steel nitriding parameters, chromosome for which the hardness profile matches best the profile sought is appointing the industrial process parameters that should be customary to achieve the requested hardness of a nitriding object.

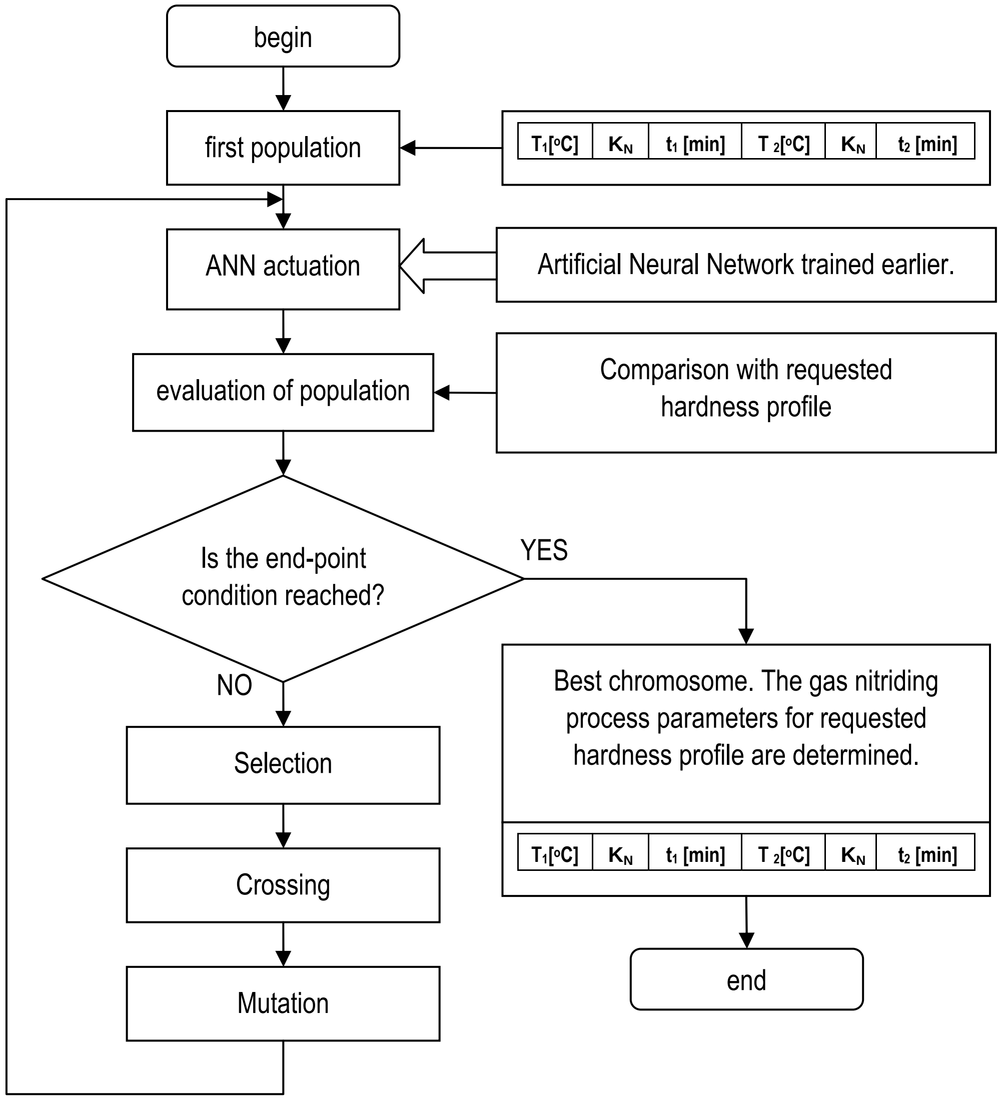

Figure 3. Flowchart of evolutionary algorithm used in experiment

Experiment – the utilization of designed algorithm for prediction of parameters of industrial gas nitriding working processes

The experiment was realized with the measurement hardness profile collected from tool parts made form 18HGT alloyed carbon steel which is European most popular nitriding grade. This steel is used with success for nitriding as well as for welding, hammersmithing, rolling and surface- of flame-hardening. At the first stage the required hardness profile is set to software, as it is shown on figure 4., and after that the evolutionary parameters, described in previous section is activated. The figure 5., shows the software during the evolutionary calculation procedure which was repeated twice. The algorithm stops when the fitting error, which is the absolute difference between required profile and the determined one by ANN, is non-changeable during 25 populations.

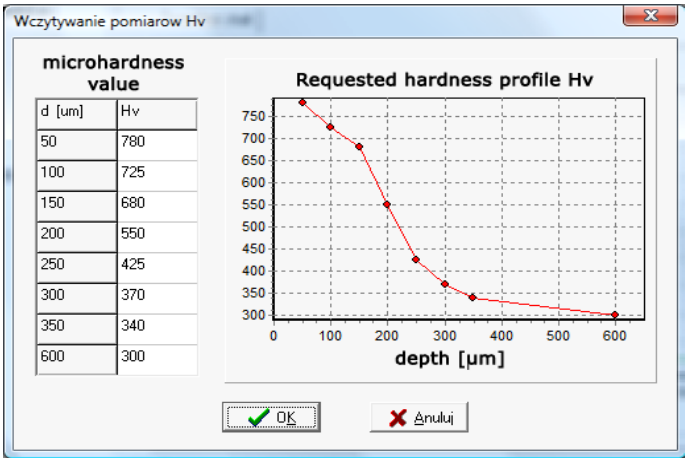

Figure 4. The software dialogue form to put the demand hardness profile in

The result of each actuation of algorithm is different – in presented case the dispersion of fitting error is between ~31÷62 (Figure 5.). Because the difference between calculated errors is so huge each time the algorithm is actuated, there is a high probability that the global minimum of error wasn't reached by the evolutionary algorithm and the calculations should continuously as long as the error is not changeable by 50 populations, for example.

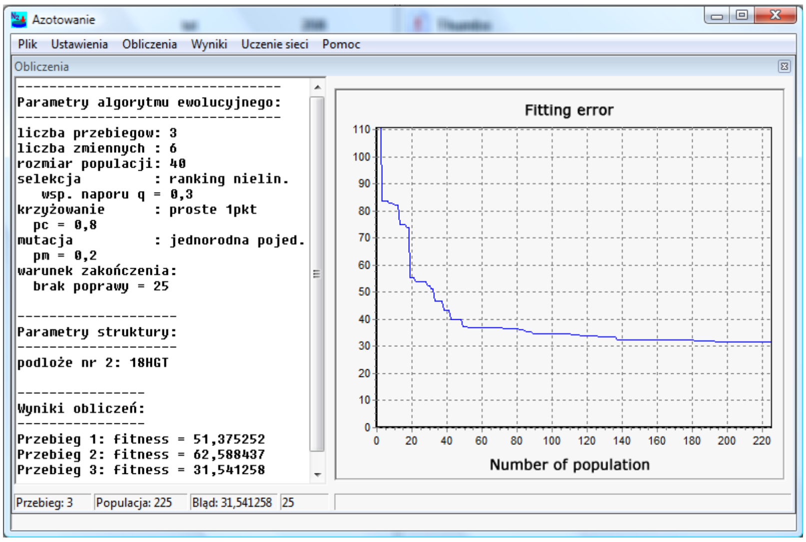

Figure 5. The screenshot of designed software window that shows the dependences of the fitting error of the best chromosome in particular population

Although the predicted harness profile for case the error is equal to 31.541258 is very similar to requested one (figure 6.). In principle the predicted profile is a very good approximation of requested one, which is conditioned by a nature of backpropagation neural network used by authors. The nitriding parameters predicted by designed software are presented on the left side of software window shown on figure 6. The significant to explain is fact that some of calculated parameters, for example time and especially temperature of process, don't have to be determined exactly. The expected accuracy is rank of 5°C, because there is hard to hold the constant temperature up during the nitriding process. Therefore the value of 571.1°C can be understood as 570°C. The duration of gas nitriding process should be round up because, as it can be read from table 1., longer time secure better hardness. In fact those variables should be rounded by the algorithm himself and they could be represented by integer's data. It is easy to see that the goal function developed in evolutionary algorithm can be defined different. In approach authors presents the aim is to minimize the absolute difference between predicted hardness profile and the sought one. In other approach it could minimize not only the fitting error, but the production cost calculated from appointed process parameters also [Słowik 2004, 2008].

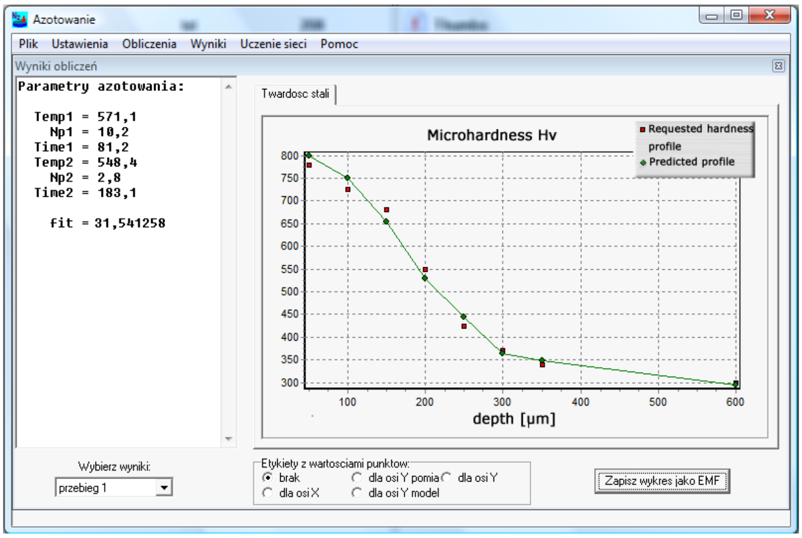

Figure 6. The result window with drawn chart which compare the requested hardness profile with predicted one

Conclusion

The work presented covers the concept of unconventional designing methods, which is use the combined artificial intelligence methods in application to predict the gas nitriding process being very popular in industry. The reason to choose such approach was numerical limitations which occur during calculations of nitriding model with the help of analytical models. Developed system of evolutionary algorithm combined with artificial neural network, as a mathematical model for determination of goal function, makes possible to determine the changes of the parameters of the gas nitriding process on the basis of the required hardness profile in the layer nitrided. The problem solved on the example of gas nitriding, i.e. determination of the process parameters which guarantee the required final result, constitutes one of the key issues of surface layer engineering. It is possible to calculate and minimize the total cost of described manufactory process, by modification of the goal evolutionary algorithm's goal function. The total calculation time ends in maximum 3 minutes, so a person interested may be informed of order cost without more ado. Hardness profile for predicted parameters is nearly identical with requested one, but in further step authors want to verify the method developed, which wasn't done yet.

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