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Using of genetic programming in engineering

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Abstract. Intelligent systems are process coupled with robotics in industrial usually settings, though they may be used as diagnostic systems connected only to passive sensors. In this paper we use a new method which combines an intelligent genetic algorithm and multiple regression to predict the hardness of hardened specimens. The hardness of a material is an important mechanical property affecting mechanical properties of materials. The Microstructures of the hardened specimens are very complex and cannot be described them with the classical Euclidian geometry. Thus, we use a new method, i.e. fractal geometry. By using the method intelligent-system, genetic programming and multiple regression, improved production the process laser-hardening increases because of the decreased time of the process and, the improved increased topographical property of the used materials. The genetic-programming modelling results show a good agreement with teh measured hardness of the hardened specimens.

Keywords: genetic programming, engineering, complex geometry structure,

Uporaba genetskega programiranja v inženirstvu

Inteligentni sistemi naj bi se po navadi povezali skupaj z robotiko v nastavitvah industrijskih procesov, čeprav so lahko sistemi za diagnostiko povezani samo za pasivne senzorje. V tem članku bomo uporabili metodo, ki združuje inteligentne genetske algoritme in multiplo regresijo za napoved trdote kaljenih vzorcev. Trdota materiala je pomembna mehanska lastnost, ki vpliva na mehanske lastnosti materialov. Mikrostrukture kaljenih vzorcev so zelo kompleksne in jih ne moremo opisati s klasično evklidsko geometrijo. Zato smo uporabili novo metodo, fraktalno geometrijo. Z metodo inteligentnega sistema, genetskim programiranjem in multiplo regresijo smo povečali proizvodnjo pri laserskem kaljenju, saj smo skrajšali čas procesa in povečali topografsko lastnost materiala. Rezultati modeliranja genetskega programiranja se dobro ujemajo z izmerjenimi vrednostmi trdote kaljenih vzorcev.

1 INTRODUCTION

Intelligent systems need to be adaptive to solve problems as creatively as possible with a minimal human input. They generally follow a sequence of events in diagnosing and addressing a potential problem. First, the system identifies and defines the problem. Intelligent-system engineering (ISE) is a blanket term used to refer to a variety of Artificial Intelligence (AI) approaches, including neural networks, evolutionary algorithms, model-based prediction and control, case-based diagnostic systems, conventional control theory, and symbolic AI. The term intelligent-system engineering is most frequently used in the context of AI applied to specific industrial challenges such as optimizing a process sequence in a sugar factory. In this paper we propose a method which combines an intelligent genetic algorithm and multiple regression to predict the hardness of hardened specimens.

Many objects observed in nature are typically complex, irregular in shape and thus cannot be described completely by the Euclidean geometry. The Fractal geometry [1] is becoming increasingly popular in material science to describe complex irregular objects. The Fractal structure was found in robot laser hardening [2]. The key of the fractal geometry is the fractal dimension [3-7] which describes, the complexity

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of the geometrical microstructure. We calculated it for the microstructure of the robot laser specimens [8, 9]. Different tool steels are widely used in industrial applications based on good performance, wide range of mechanical properties, machinability, wear resistance, and how cost cheapness. By laser remelting the surface of the materials, we can significantly improve their wear properties, better than with the inductive hardening. Robot laser surface [10] remelting is one of the most promising techniques for surface modification of the microstructure of a material to improve its wear and corrosion resistance. The Laser hardening [11] is a metal surface treatment process complementary to the conventional flame and induction hardening processes. A high-power laser beam is used to rapidly and selectively heat a metal surface to produce the hardened case depths of up to 1.5 mm with a hardness value of up to 65 HRc.

The aim of the paper is to outline the possibilities of applying genetic programming and multyple regression to predict the hardness after, a robot laser heat treatment and to assess, their perspective use.

2 MATERIAL PREPARATION

First, we hardened the tool steel with a robot laser cell. We changed two parameters, i. e. speed v ∈ [2, 5] mm/s in steps of 1 mm/s, and temperature T ∈ [1000, 1400] °C. After hardening, we polished and etched all specimens. A detailed characterization of their microstructure before and after surface modifications was conducted using a field emission-scanning electron microscope (SEM), JEOL JSM-7600F. The SEM pictures (Fig. 1) were converted into binary images from which we calculated the fractal dimensions. They were determined using the Hurst exponent H estimation method.

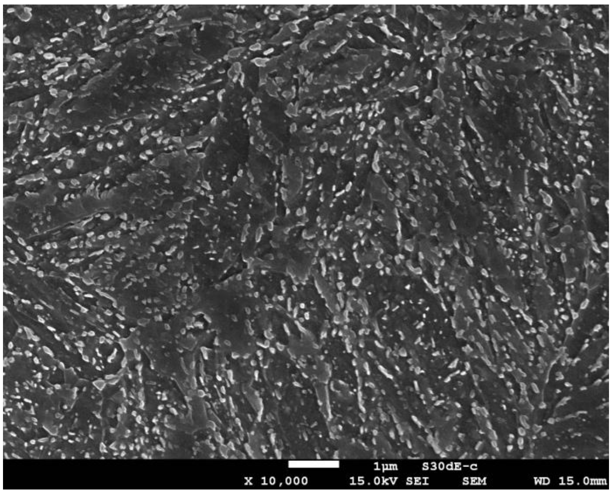

Figure 1. Fractal structure of a robot-laser-hardened specimen

3 METHOD

To analyse the results, we used an intelligent system method, namely genetic programming and multiple regression. Genetic Programming (GP) is a method used to *evolve computer programs*. GP is inspired by the biological evolution. It is a machine-learning technique used to optimise a solution based on a fitness score. Solutions are represented by *chromosomes* encapsulating parameters, and these chromosomes change with iterations to get closer to a desired representation. GP has many applications; arm, traffic optimization problem and its solving [12], etc. The hardness prediction is based on the available function genes (i.e., basic arithmetical functions) and terminal genes (i.e., independent input parameters, and random floating-point constants). In the presented case, the models consist of the following function genes: addition (+), subtraction (-), multiplication (*) and division (/); and the following terminal genes: air temperature [°C] (X1), speed of hardening [m/s] (X2), fractal dimension (X2), and basic hardness (X4). Fig. 2 show one of the randomly generated mathematical models.

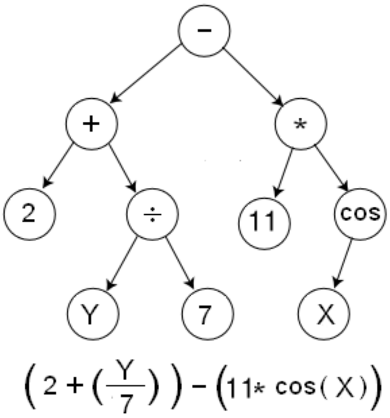

Figure 2. GP Model

The following evolutionary parameters were selected to process the simulated evolutions: 500 for the size of the population of organisms, 100 for the maximum number of generations, 0.4 for the reproduction probability, 0.6 for the crossover probability, 6 for the maximum permissible depth in the creation of the population, 10 for the maximum permissible depth after the operation of crossover of two organisms, and 2 for the smallest permissible depth of organisms in generating new organisms. Genetic operations of reproduction and crossover were used. To select organisms the tournament method with the tournament size of 7 was used.

The Multiple linear regression attempts to model (1) the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the observed data. Every value of the independent variable *x* is associated with the value of the dependent variable *y*. Formally, the model for the multiple linear regression the given *n* observations is

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots \beta_p x_{ip} + \beta_i \text{ for } i = 1,2, \ldots n. \quad (1)$$

In the least-square model, the best-fitting line (Figure 2) for the observed data is calculated by minimizing the sum of the squares of the vertical deviations from each data point to the line (if a point lies exactly on the fitted line exactly, then its vertical deviation is 0).

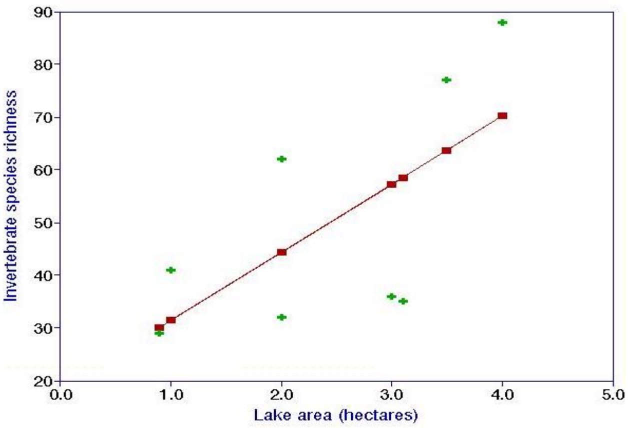

Figure 3. Multiple regression

4 RESULTS

In Table 1, the parameters of the hardened specimens that impacting the hardness are presented. We mark specimens from P1 to P16. Parameter X1 presents the parameter of temperature [°C], X2 presents the hardening speed [mm/s], X3 presents the fractal dimension and X4 presents the base hardness (hardness before hardening). The last parameter is the measured hardness of the laser-hardened robot specimens. With the fractal dimension we describe the complexity of the hardened specimens. In Table 1 we can see that specimen P15 has the largest fractal dimension, i. e. 2.433. Thus specimen P15 is the most complex. Specimen P1 has the highest hardness after hardening, that is 60 HRc. In table 2, the experimental and prediction data are presented. S stands for the name of the specimens and ED presents for the experimental data. Predictions with the multiple regression are presented in columns PR and those with GP in columns P GP. The measured and predicted surface hardness of the laser-hardened robot specimens is shown in the graph in Fig. 4. The regression model is presented in equation (2). The GP model is presented in equation (3). The GP model presents a 1.33% deviation from the measured data, which is less than the regression model, presenting a 2.44% deviation.

$$Y = 58{,}39271272 + 0{,}00880226 * X1 + 0{,}702872611 * X2 - 5{,}677509178 * X3 - 0{,}034312945 * X4 \quad (2)$$

$$Y = 48, 9908+0, 64137*X2 -1, 71943 \_X3 +0, 00874*(X1 +0, 00874*X3*(-2, 79749+X1+(-1,71943+0, 00874*X1) X3* X3* X3 * X3+(-1, 71943+0, 00874*X1)*(-1,71943*X2+X3*X3)))-0,03422*(-5,15829 -1,71943*(0,00874*X1+0,00874*X2)-1, 07806*X2-3,43886*X3+0,4137*X2*X3*X3+X3*(-1,71943+0,00874*X1-0,00942224*X2+(-3, 13886+X2)*(-1,71943* X2+0, 00874* X3)-1,71943*X3 + 0, 00874* X1*X3 - 1, 17943*X3 *X3)* (-3, 45389+0, 64137*(X2+0,00874*(X1-1,7943*X3))-1,07806*X3* X3)+X4) \quad (3)$$

Table 1. Parameters of the hardened specimens

S	X1	X2	X3	X4	Y
P1	1000	2	2.304	34	60
P2	1000	3	2.264	34	58.7
P3	1000	4	2.258	34	56
P4	1000	5	2.341	34	56.5
P5	1400	2	2.222	34	58
P6	1400	3	2.388	34	57.8
P7	1400	4	2.250	34	58.1
P8	1400	5	2.286	34	58.2
P9	1000	2	2.178	60	57.4
P10	1000	3	2.183	58.7	56.1
P11	1000	4	2.408	56	53.8
P12	1000	5	2.210	56.5	56
P13	1400	2	2.257	58	55.3
P14	1400	3	2.265	57.8	57.2
P15	1400	4	2.433	58.1	57.8
P16	1400	5	2.289	58.2	58

Table 2. Experimental and prediction data

S	ED	P R	P GP
P1	60.0	54.3531	58.3646
P2	58.7	55.28307	57.4004
P3	56.0	56.02001	56.7468
P4	56.5	56.25165	56.5463
P5	58.0	58.33956	58.0556
P6	57.8	58.09996	58.7735
P7	58.1	59.58633	57.447
P8	58.2	60.08481	58.5599
P9	57.4	54.17633	56.6413
P10	56.1	54.89542	56.1589
P11	53.8	54.4135	56.377
P12	56.0	56.22336	55.9996
P13	55.3	57.31733	57.562
P14	57.2	57.98165	56.856
P15	57.8	57.7204	57.7407
P16	58.0	59.23741	57.7365

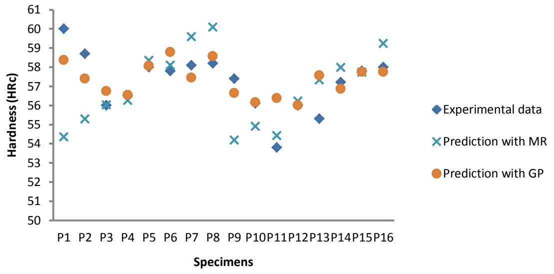

Figure 4. Measured and predicted porosity of teh hardened specimens

5 DISCUSSION

Compared to other approaches, the fractal approach is found to be more appropriate to characterise the complex and irregular surface microstructures observed on the surface of the robot-laser hardened specimens, it can be effectively utilized in predicting the material properties from the fractal dimensions of the microstructure. Specimen P15 has the largest fractal dimension, 2.433, thus specimen P15 is the most complex. A statistically significant relationship was found between, the hardness, parameters of the robot laser cell and image analysis with the fractal geometry. With the fractal dimension we describe complexity of the hardened specimens. Also, analysis of the SEM images of the robot laser-hardened specimens is an interesting approach. Specimen P1 has the highest hardness after hardening, that is 60 HRc. We use the method intelligent-system to predict hardness of the robot laser-hardened specimens. Using the intelligent system method, GP and multiple regression, we increase the laser-hardening production process, decreasing the time of the process and improving the material topographical property. The GP model allovs for 1.33% deviation from the measured data which is less than that of the regression model which presents a 2.44% deviation.

6 CONCLUSSION

The paper proposes the use of a new method of intelligent system, genetic programming and multiple regression to predict the hardness of hardened specimens. The fractal geometry is used to describe the complexity of the robot laser hardened specimens. The original characteristics of the method are:

1. The structure in the robot laser-hardened specimens is fractal.
2. The fractal dimension is used to describe the complexity of the hardened specimens.
3. The optimal fractal dimension of different parameters of the robot laser-hardened tool steel is inditified.
4. The fractal dimension varies between 2 and 3.
5. To predict the hardness of the hardened specimens, a genetic algorithm and multiple regression are used.
6. The genetic programming modelling results show a good agreement with the measured porosity of the hardened specimens.

In future we plan to use the intelligent-system model to predict more further mechanical properties of the robot laser-hardened specimens.

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