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A new statistical pattern recognition method and a new sequence hybrid method of intelligent systems

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Abstract. In the paper we use methods of the intelligent system to predict the complexity of the network fracture of hardened specimens. We use a mathematical method of the network theory and fractal geometry in engineering, particularly in laser techniques. Moreover, using the fractal geometry, we investigate the complexity of the network fracture of the robot-laser hardened specimens, and analyze specimens hardened with different robot laser-cell parameters, such as the speed and temperature. Laser hardening is a metal-surface treatment process complementary to the conventional and induction hardening process. In this paper, we present a new method for the statistical pattern recognition using statistical techniques in analyzing the data measurements in order to extract information and take oppromate decisions in particularly mechanical engineering. To predict of the complexity of the network fracture of hardened patterns, we use multiple regression, neural network and support vector machine and to predict topographical property of hardened specimens, we use a hybrid method of machine learning.

Keywords: pattern recognition, hybrid system of machine learning, mechanical engineering,

Nova metoda ra statistično razpoznavanje vzorcev in nova sekvenčna hibridna metoda inteligentnih sistemov

V članku bomo uporabili metode inteligentnega sistema za napovedovanje kompleksnosti mrežnega loma kaljenih vzorcev. Uporabili bomo matematično metodo teorije omrežja in fraktalno geometrijo v inženiringu, še zlasti v laserskih tehnikah. Poleg tega smo s fraktalno geometrijo analizirali kompleksnost omrežja lomov robotskih lasersko kaljenih vzorcev. Analizirali smo vzorce, kaljene z različnimi parametri robotske laserske celice, in sicer parameter hitrosti in temperature. Lasersko kaljenje je proces toplotne obdelave kovinskih površin, ki dopolnjuje konvencionalne procese kaljenja in indukcije. V tem članku predstavljamo novo metodo za statistično prepoznavanje vzorcev. Statistično prepoznavanje vzorcev se nanaša na uporabo statističnih tehnik za analizo meritev podatkov, da bi pridobili informacije in utemeljili odločitve. Ta rešitev predstavljenega problema ima aplikacije v strojništvu. Za napovedovanje kompleksnosti omrežja loma kaljenih vzorcev uporabljamo multiplo regresijo, nevronske mreže in metodo podpornih vektorjev. Za napoved topografskih lastnosti kaljenih vzorcev uporabljamo hibridno metodo strojnega učenja.

1 INTRODUCTION

One of the main requirements for laser hardening [1-2] is the uniformity of the depth of the hardened zone and the absence of defects on the surface. To achieve such results, it is necessary to use a uniform surface heat source. However, a real laser beam of a single and a multi-mode type, can not provide such uniform heating. We need devices that transform the structure of the laser beam into a homogeneous distribution. They can be opto-mechanical scanning systems that do not change the mode composition of the beam, but repeatedly move it along the heating zone and create an average uniform thermal source during the hardening

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of the thermal cycle. In this case, in the heat problem of quenching, it is necessary to take into account not only the spatial, but also the time structure of the heat source. To calculate the laser hardening modes with scanning, we use an earlier substantiated procedure for the transition from a three-dimensional problem of heating a metal by a bounded moving surface heat source to an equivalent one-dimensional thermal problem of heating a metal by an infinite surface thermal source, supplementing it with parameters characterizing the scanning regime.

A big problem in industrial processes is manual setting of the CNC parameters to achieve the best desired results, because this is a very time-consuming process. Heat treatment is a quicker way to access information according to the desired specifications. It is necessary to develop intelligent systems based on individual samples to disclose the topological properties of a material after heat treatment. Recently, authors [3] suggest fracture simulation using a mesh-dependent fracture criterion. In the paper we present a new hybrid method of intelligent systems which allows us to obtain results more quickly. So, our focus is on the fracture topological properties of robot laser-hardened specimens [4]. It is very important to research the effect of heat treatment on the microstructure, fracture and wear resistance. Authors [5] use a known model of the fracture mechanics. It contains a fitting parameter which governs the interplay between the fracture mode in order to find, an optimal agreement between the data and analytical predictions by developing relatively simple equations.

Among the disciplines and methods, discrete mathematics network graphs [6], and especially algorithms on graphs, find a most broad application of programs on the world. Between the concept of graphs and the concept of binary relations there is a deep communication can to tell, what this equal volume notions. Introduction of special terms and notations simplifies the exposition theory and makes it more understandable. The name graph implies availability of graphic interpretations. It allows to visually identify the essence of business at an intuitive level of complementing and decorating an exhausting text evidence and a complex formula. The number of graphs associated with graphs is very broad. This is the study of the structure and properties of the network, the study of special graph classe, construction of fast algorithms for graph solving problem, etc.

Machine learning [7] is an extensive subsection of the artificial intelligence that studies methods of constructing algorithms capable of learning. There are two types of training. Learning by the use of precedents, i.e. inductive learning, is based on the identification of general patterns of the private empirical data. Deductive learning involves formalizing the knowledge of experts and transferring it to the computer as a knowledge base. Deductive learning is usually referred to the field of expert systems, so the terms machine learning and training by the using precedents can be considered synonymous. Machine learning is at the intersection of the mathematical statistics, optimization methods and classical mathematical disciplines, but it also has its own specifics associated with the problems of the computational efficiency and retraining. Many methods of inductive learning were developed as an alternative to classical statistical approaches. Many methods are closely related to information extraction and data mining. Machine learning is not only a mathematical but also a practical engineering discipline. Aa rule pure theory does not immediately lead to methods and algorithms applicable in practice. To make them work well, we have to invent additional heuristics to compensate for the inconsistency of the assumptions made in theory by the conditions of real problems. Virtually, no research in machine learning can do without an experiment on a model or real data, confirming the practical working capacity of the method.

Statistical pattern recognition [8] is a term used to cover all stages of an investigation from problem formulation and data collection through to discrimination and classification, assessment of results and interpretation. Pattern recognition as a field of study developed significantly in the 1960s. It was very much an interdisciplinary subject covering developments in the areas of statistics, engineering, artificial intelligence, computer science, psychology and physiology, among others. In the paper we present a new method for statistical pattern recognition.

Fractal geometry [9], one of the tools of the chaos theory, is used to study phenomena that are chaotic only from the point of view of the Euclidean geometry and linear mathematics. Fractal analysis has revolutionized the nature of research conducted in a myriad of different fields of science: meteorology, medicine, geology, economics, metaphysics. This new promising strategy has the potential of the profound impact on all of us, greatly changing our lives. Fractal analysis is a new powerful paradigm which we can use in material science.

This paper deals with hardened alloys tested at a room temperature and prediction of the topographical property of hardened specimens with an intelligent system using a hybrid method. The aim is to determinate the parameters of a robot laser cell providing a minimal fracture after a hardening process and to show the possibilities of applying the method prediction for the topographical property after robot laser heat treatment and to assess their perspective use in this field. The current models enable the prediction of the final fracture on the basis of decisive parameters of the laser beam affecting these properties, using them intelligent system model reduces the time, cost and process work, increases the competitiveness, allows a more rapid progress in the process of heat treatment of materials and improves the economic potential.

2 MATERIALS PREPARATION

A tool steel is hardened with a robot laser cell and forged with a laser at different speeds and powers. Two parameters are changed, i.e. the speed v ∈ [2, 5] mm/s and temperature T∈ [1000, 1400] °C. The surface of a metallographic specimen is prepared by various polishing method. After such preparation scanning electron microscopy is used. Fig. 2 shows microstructure fracture of a robot laser-hardened specimen. The Images are made using a field emission scanning electron microscope SEM (*JMS-7600F JEOL* Company). Using only the metallographic techniques, a skilled technician can identify alloys and predict material properties.

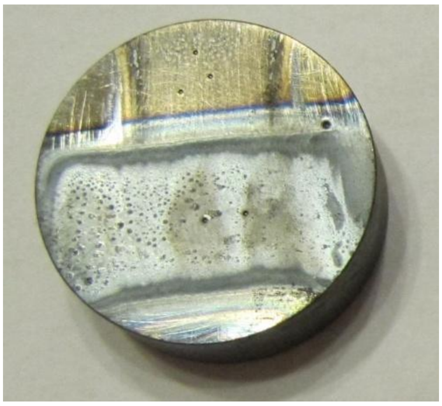


Figure 1. Hardened specimen.

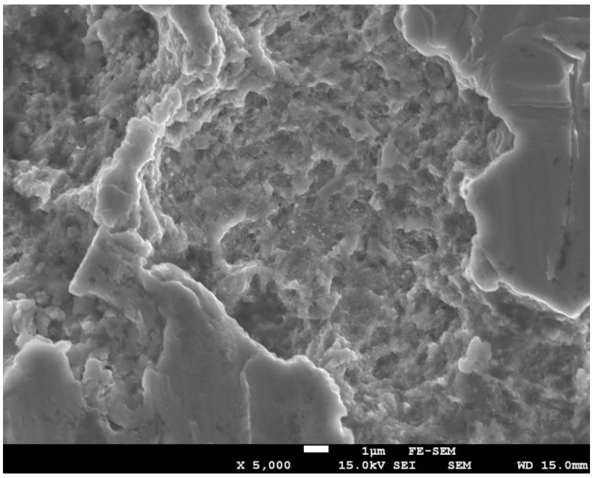


Figure 2. SEM electron image of the intergranular fracture of robot laser hardened specimen.

3 METHODOLOGY

There are many freely available source codes for pattern recognition and machine learning algorithms, such as non-planer grain boundaries in microstructure, the geometry of the crack paths, crack fronts and fracture surface texture demonstrating the graph topological characteristics. However, classical fracture mechanics assumes smooth fracture surfaces or planer cracks and the formulation of material properties like fracture energy based on the planer Euclidean geometry. Thus, the fracture energy calculated using the Euclidean surface concepts is often found to be lower than the experimentally measured values. The fracture features, like voids, tortuosity of the crack path, crack branching, and manifestations of fracture surface undulations, like striations, riverlines and other such microductilities, are responsible for increasing the actual fracture surface area and creating fracture surface roughness.

On the microstructure of the robot laser-hardened specimens (Fig. 3.a)), the fracture (Fig. 3. b)) and the number of each island of the fracture are determinated and all neighbour nodes are connected by links (Fig. 3. d)). This number presents the weight of the network. Then, the number of polygons presenting the fracture and the number of the line of all polygons are found. Topological property B of the network is now calculatied (Fig. 3. d)).

B is the number of polygons / number of all lines of all polygons

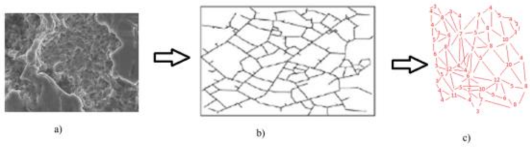


Figure 3. Method for pattern recognition by using the network theory.

Figure 4 shows a the fractographic image of a robot laser-hardened fracture surface obtained with circular void features of a homeomorphic (regular) fractal model. Fractal dimensions such complexity of the network fracture models is quantified. Fig 4.a presents a fractograph of a robot laser-hardened fracture surface. Fig. 4.b shows a schematic presentation and in Fig.4.c a fractal model of a robot laser-hardened fracture surface. By analyzing of the fractographic images, these features identified and fractal models of these features are employed to find out the true fracture surface area to calculate the surface energy. Fractal dimensions such fractal model are quantified by dimension.

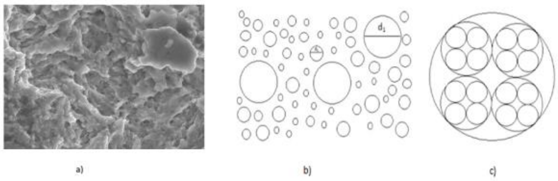


Figure 4. Homeomorphic (regular) fractal model for fractographic image of the fracture surface.

To analyze the results, we use intelligent systems methods (neural network, multiple regression and support vector machine).

The artificial neural networks (ANNs) investigated [10] of how they are used for machine learning or applied for speech and object recognition, image segmentation, language and human motion modeling, etc. The first artificial neural network was invented in 1958 by the psychologist Frank Rosenblatt. It was named Perceptron and was intended to model how the human brain processes visual data and learnes to recognize objects. Since them other researchers have used similar ANNs to study human cognition. We use backpropagation, cross validation and five layer neural network. The speed of learning is 0.4, inertial coefficient is 0.5, test mass tolerance is 0.02 and the learning tolerance set is to 0.03.

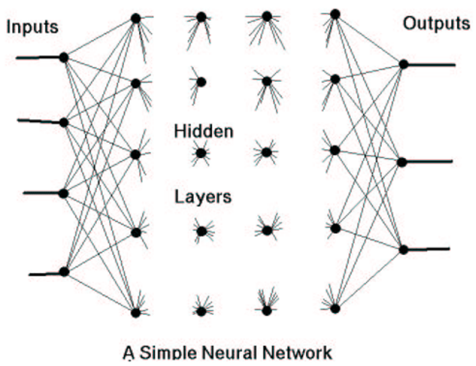


Figure 5. Symbolic presentation of an artificial neural network cell.

Multiple regression is widely used in solving the problems of the demand and stock returns, in studying the function of the production costs, in macroeconomic calculations and in solving a whole series of other issues of econometrics as well as in mechanical engineering. The main purpose of multiple regression is to build a model with a large number of factors to determine the impact of each of them separately as well as their combined impact on the modeled indicator. Multiple regression helps to solve the problem of using more than one predictive variable. In our study, one criterion and two or more predictor variables are used. This force is displayed in the multiple regression formula for the input data, which is an extended version of the simple regression formula:

$$y = f(X1, X2, ..., Xm) + E,$$

where y is the dependent variable (the resultant attribute), *X1*, *X2*, ..., *Xm* are independent explanatory variables (feature factors), *E* is a perturbation or stochastic variable that includes the impact of unaccounted factors in the mode.

The Support Vector Machine belongs to the category of the university direct distribution networks, both the multilayered perceptron and the network are based on radial basis functions. The idea of the support vectors consists of constructing a hyperplane acting in the quality of the surface of solutions that maximally separates the positive and negative examples from the training set the gesture. More particularly, the support vector machine is approximating the implementation of the method of minimizing the structure risk, which is based on the fact that the level of the error learning machine on a test set can be in a form of a sum of the learning errors and a term depending on the Vapnik-Chervonenkis measurement. In the case of shared sets, the value "zero" for the first summand and the value of the second term is minimized. Therefore, the support vector machine can provide a high quality generalization, without a priori knowledge of the subject specific task. We use a cross validation of the v-SVM Type with a 0.90 regression cost (C). For the optimization parameters we use a 110 iteration limit and numerical tolerance a 0.002. We use Kernel $(g \times x \times y + 0.12)^3$ and g is auto.

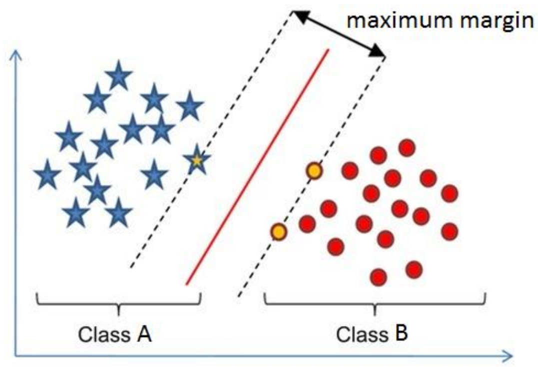


Figure 6. SVM.

In recent years, Intelligent computing has attracted many scientists for being a powerful and novel intelligent techniques for solving unlimited number of complex real-world problems with different methods. One of such methods is hybrid evolutionary computation [13]. It is a generic, flexible, robust, and versatile method for solving complex global optimization problems as well as for implementing practical applications. We present a new hybrid method. Hybrid methods are connected in series in the direction of the entrance to method n. Each method works independently. The results of input method 1 are transferred to input method 2, the results of input method 2 are transferred to input method 3, the results of input method 3 are transferred back to input method 2, the results of input method 2 are transferred back to input method 1 and the results of input method 1 are transferred to input method 3. Method 1 M1 presents a multiple regression, Method 2 M2 presents a neural network and Method 3 M3 presents a support vector machine.

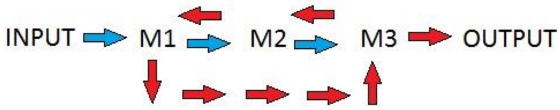


Figure 7. Sequences hybrid.

4 RESULTS AND DISCUSSION

In Table 1, the parameters of hardened specimens impacting on the fracture are presented. The specimens from P1 to P16 are merked. Parameter X1 is the temperature parameter [°C], parameter X2 is the speed of hardening [mm/s] and parameter X3 is topological property B of the graph. The last parameter Y is the complexity of the network fracture of the laser-hardened robot specimens fractal dimension. In Table 1, we can see that specimen P15 has the largest topological property B, 0.2028. Specimen P5 has most of the complexity of the network fracture after hardening, which is 1.8065. Table 2 presents experimental and prediction data regarding the surface fracture of the laser-hardened robot specimens. Column S presents patterns, column ED presents experimental data, column P MR presents prediction with a multiple regression, column P NN presents prediction with neural network and column P SVM presents prediction with support vector machine. Column P H presents prediction with the method of the sequence hybrid system. The measured and predicted complexity of the network fracture of the laser-hardened robot specimens is shown in the graph in Fig. 8. The neural multiple regression presents a 14.74% deviation from the measured data. The neural network model presents a 5.31% deviation from the measured data. The support vector machine model presents a 15.16% deviation from the measured data. The sequence hybrid presents a 10.69% deviation from the measured data.

Table 1. Parameters of the hardened patterns

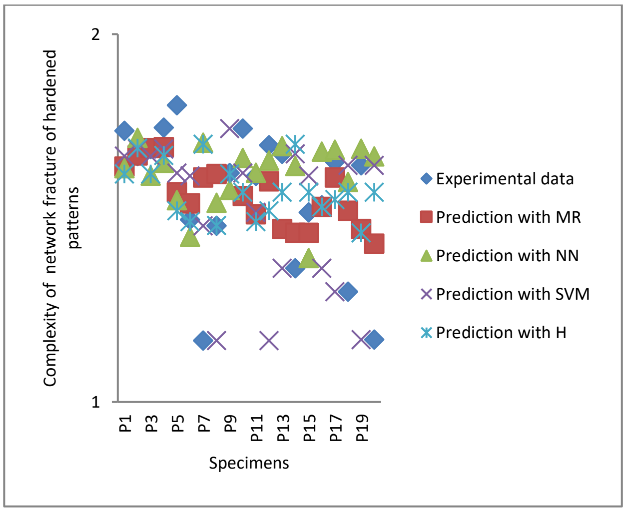
Specimen	X1	X2	X3	Y
P1	1000	2	0.1920	1.7365
P2	1000	3	0.1887	1.6680
P3	1000	4	0.1882	1.6871
P4	1000	5	0.1951	1.7458
P5	1200	2	0.1852	1.8065
P6	1200	3	0.1990	1.4956
P7	1200	4	0.1875	1.1664
P8	1200	5	0.1905	1.4784
P9	1300	2	0.1815	1.6220
P10	1300	3	0.1819	1.7426
P11	1300	4	0.2007	1.6142
P12	1300	5	0.1842	1.6982
P13	1400	2	0.1881	1.6743
P14	1400	3	0.1888	1.3634
P15	1400	4	0.2028	1.5155
P16	1400	5	0.1908	1.5342
P17	1000	0	0.1860	1.6528
P18	1200	0	0.1863	1.2996
P19	1300	0	0.1884	1.6427
P20	1400	0	0.1872	1.1693

Table 2. Experimental and prediction data

S	ED	P MR	P NN	P SVM	P H
P1	1.7365	1.6402	1.635	1.6681	1.6194
P2	1.6680	1.6744	1.718	1.6870	1.6936
P3	1.6871	1.6979	1.615	1.6684	1.6194
P4	1.7458	1.6936	1.650	1.6871	1.6736
P5	1.8065	1.5762	1.548	1.6224	1.5164
P6	1.4956	1.5459	1.449	1.6142	1.4947
P7	1.1664	1.6109	1.705	1.4784	1.6979
P8	1.4784	1.6213	1.541	1.1664	1.4756
P9	1.6220	1.5453	1.576	1.7426	1.6194
P10	1.7426	1.5655	1.663	1.6214	1.5655
P11	1.6142	1.5164	1.623	1.5155	1.4947
P12	1.6982	1.6002	1.656	1.1663	1.5164
P13	1.6743	1.4756	1.695	1.3634	1.5655
P14	1.3634	1.4947	1.641	1.6743	1.6978
P15	1.5155	1.4636	1.391	1.6142	1.5655
P16	1.5342	1.5305	1.680	1.3634	1.5287
P17	1.6528	1.6194	1.686	1.2996	1.5459
P18	1.2996	1.5287	1.598	1.6427	1.5745
P19	1.6427	1.4759	1.688	1.1693	1.4636
P20	1.1693	1.4356	1.667	1.6427	1.5655

Model of the multiple regression

$$Y = -4.4822\times10^{-4} \times X1 + 2.1697\times10^{-2} \times X2 - 3.7669 \times X3 + 2.7683$$



The fracture structure of a material is an important mechanical property that affects the material hardness. The Euclidian geometry can be applied to describe the fracture of the hardened specimens because the fracture is very complex. Here, the fractal geometry is used to describe the complexity of the network fracture of the robot laser-hardened specimens. In the paper we describe how the parameters (speed and temperature) of the robot laser cell affect the fracture of metal materials using a new method, i.e. the network theory. So, with the fractal dimension we describe the relationship between the topographical property and the parameters of the robot laser cell. The fracture unsiderable affects on the mechanical properties of a material. The optimal parameters of the robot laser cell that give a minimal complexity of the network fracture. The fractal geometry approach is more appropriate to characterization of complex and irregular surface microstructures observed in the surface of robot laser-hardened specimens and can be effectively utilized for predicting the properties of a material from the fractal dimensions of the microstructure. Using the network theory for a series of digitized surface microstructures of the robot laser surface-modified specimens indicates that there cn be useful correlations between the topological properties and the surface microstructure features, such as complexity of the network fracture. A fracture is a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. There is a statistically significant relationship between determining a fracture using the SEM microstructure method, parameters of the robot laser cell and SEM image analysis with the network theory. Moreover, SEM image analysis of the robot laser-hardened specimens is an interesting approach. We use four methods of the intelligent system to predict the complexity of the network fracture of the robot laser-hardened specimens. We show that the model of the neural network provides a better predict result. We present a new hybrid method of machine learning to predict the topographical property of hardened patterns. This contribution is important for technologists, in their considering numerous CNC machine parameters to get the best desired results.

5 CONCLUSION

The wear resistance of cast irons and alloys is noteably increased under sliding friction conditions after with a continuous laser treatment. The increase in the wear resistance of cast irons after a laser treatment does not depend on the structural and phase composition but also on the minimized friction conditions due to the graphite retained in the laser impact zone which increases the friction resistance of steels and some other alloys in an alkaline and acidic environment. The paper presents the use of on intelligent system method to predict complexity of a fracture network of hardened specimens. The network theory is used to describe the mechanical property of a fracture of a robot laser-hardened specimen. Using the presented hybrid intelligent-system method inproves the laser-hardening process by decreasing the time of the process and increasing the topographical property of materials.

6 ACKNOWLEDGEMENT

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