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USE FRACTAL GEOMETRY TO DESCRIBE FRICTION OF ROBOT LASER HARDENED SPECIMENS

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Abstract: *This paper describes some of our experience in laser surface remelting, consolidating, and hardening of steels. The process of laser hardening with remelting of the surface layer allows us to very accurately determine the depth of modified layers. In this procedure, we know the exact energy input into the material. Heating above the melting temperature and then rapidly cooling causes microstructural changes in materials, which affect the increase in hardness. Mathematics and Computer Science are very useful in many other Science. We use mathematical method, fractal geometry in engineering, exactly in laser technics. Moreover, with fractal geometry we analize complexity of robot laser hardened specimens. We analize specimens hardened with different parameters of robot laser cell. So we changed two parameters speed* $v \in [2, 5]$ *mm/s and temperature* $T \in [1000, 1400]$ *°C. In this work, we have used a scanning electronic microscope (SEM) to search and analyse the fractal structure of the robot laser hardened specimens. Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other. The present study is intended to use new method, fractal geometry to describe completely friction of robot laser hardened specimens. Finally, concept of fractal geometry is applied to characterize the microstructure and derive the useful relationship between fractal dimension and microstructural features. The modeling of the relationship was obtained by the four layer neural network.*

Keywords: *Friction, fractal geometry, robot, laser, hardening,*

1. INTRODUCTION

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

In nature we have many geometrical objects which are irregular and cannot be described with classical Euclidian geometry. Thus we need a new method for describing the complexity and irregularity of objects. A relatively new method is fractal geometry. Recently, a concept of fractal geometry which was originally developed for the analysis of irregular features in nature has been finding increased applications in the fields of materials science for the characterization of microstructures. The key to fractal geometry is the fractal dimension, which describes the complexity of a fractal and geometrically irregular microstructure. Measuring fractal dimensions has become a common practice for describing the structural properties of roughness and hardness of heat-treated materials. We use fractal geometry in laser techniques. Laser hardening is a metal surface treatment process that is complementary to conventional aim and induction hardening processes. A high-power laser beam is used to heat a metal surface rapidly and selectively so as to produce hardened case depths of up to 1.5mm with the hardness of a martensitic micro-structure, providing improved properties such as wear resistance and increased strength.

First, we hardened tool steel standard label DIN standard 1.7225 with a robot laser cell. The chemical composition of the material contained 0.38 to 0.45% C, 0.4% maximum Si, 0.6–0.9% Mn, 0.025% maximum P, 0.035% maximum S and

0.15–0.3% Mo [18]. The specimen test section was in a cylindrical form with dimensions of 25×10mm. We changed two parameters, speed v ∈ [2, 5] mm/s in steps of 1 mm/s, and temperature T ∈ [1000, 1400] °C in steps of 100 °C. After hardening, we polished and etching all specimens. Detailed characterization of their microstructure before and after surface modifications was conducted using a field emission scanning electron microscope, JEOL JSM-7600F. We used the ImageJ program (available from the National Institute of Health, USA) to analyse these pictures. On these specimens we took measurements of roughness and hardness before and after robot laser hardening.

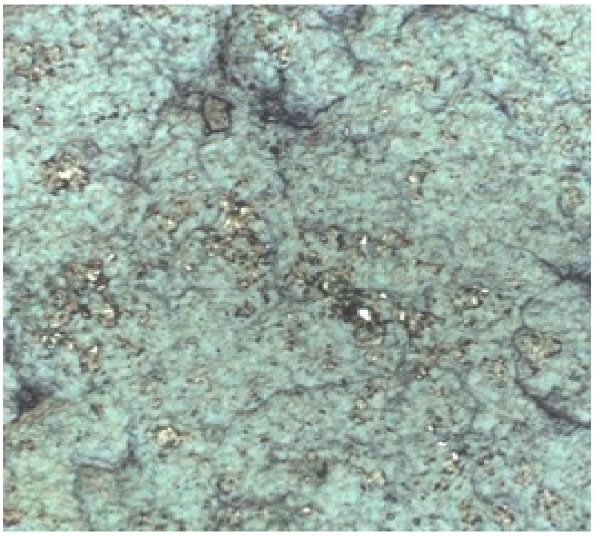


Figure 1. Microstructure before robot laser hardening

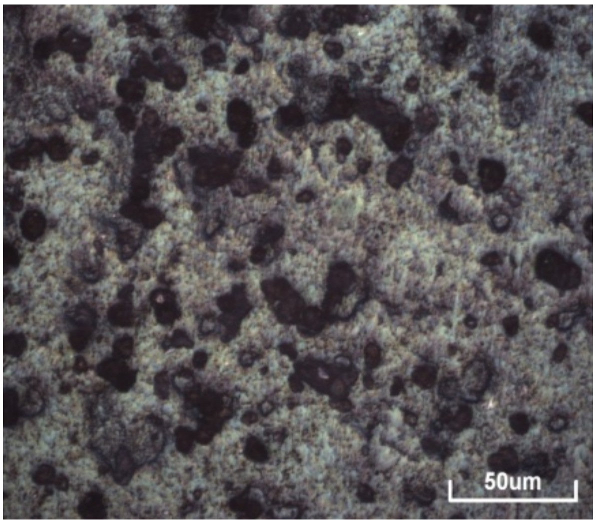


Figure 2. Microstructure of robot laser hardened specimen with 1000° C and 2 mm/s

2. MATERIALS AND METHOD

Our study was limited to tool steel of DIN standard 1.7225 (Fig. 1). The chemical composition of the material contained 0.38% to 0.45% C, 0.4% maximum Si, 0.6% to 0.9% Mn, 0.025% maximum P, 0.035% maximum S and 0.15% to 0.3% Mo.

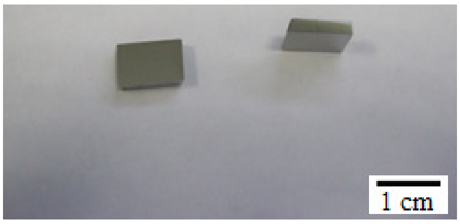


Figure 3. Transverse and longitudinal cross-section of hardened specimen

The specimen test section had a cylindrical form of dimension 25 × 10 mm (diameter × height). Specimens with porosity of about 19% to 50%, were prepared by laser technique, followed by hardening at T ∈ [1000, 1400] °C and v ∈ [2, 5] mm/s. We changed two parameters of the robot laser cell: speed v ∈ [2, 5] mm/s with steps of 1 mm/s and temperature T ∈ [1000, 1400] °C in steps of 100 °C (Fig. 2).

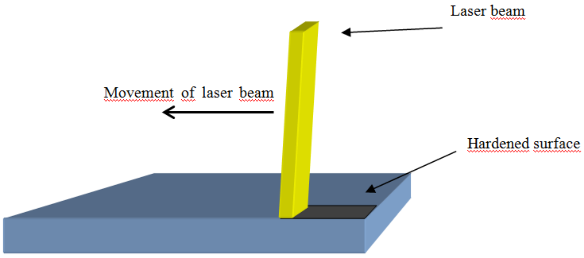


Figure 4. Robot laser hardening with different temperature and speed

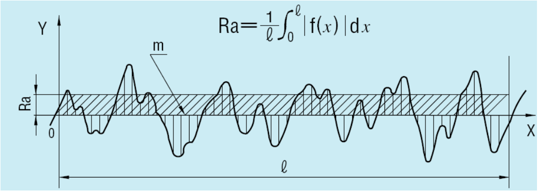
A profilometer (available from the Institute Jozef Stefan, Slovenia) was used for the measurement of the surface roughness parameter R_a (arithmetic mean deviation of the roughness profile) and hardness of the robot laser hardened specimens. SEM images were converted into binary digital images (using the public domain software, ImageJ). The fractal characterization of materials properties as an applicable and potential tool has been well documented. The key parameter in fractal geometry is the fractal dimension, D, which should be determined first before we use the concept and knowledge of fractal geometry to characterize the microstructure of the robot laser hardened specimens. We calculated the fractal dimension using image processing of the SEM pictures in combination with implementation of a box-counting method (algorithm) using the ImageJ software. The measure of the fractal object, M(L), is related to the length scale, L, through a scaling in the form of Eq. (1):

$$M(L)=L^D \qquad (1)$$

where M(L) is the surface area of a pore and D is the fractal dimension of the sample. A two-dimensional object, such as the SEM picture, can be divided into N(ε) self-similarity smaller squares, each of which is measured by the length ε. The fractal dimension can be calculated according to Eq. (2):

$$D=\ln N(\varepsilon)/\ln\varepsilon. \qquad (2)$$

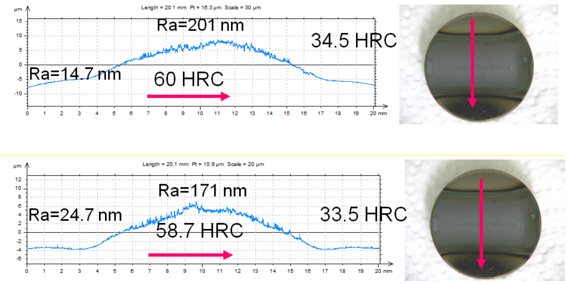
Characterization of surface topography is important in applications involving friction, lubrication, and wear (Thomas, 1999). In general, it has been found that friction increases with average roughness. Roughness parameters are, therefore, important in applications such as automobile brake linings and floor surfaces. The effect of roughness on lubrication has also been studied to determine its impact on issues regarding lubrication of sliding surfaces, compliant surfaces, and roller bearing fatigue. Finally, some researchers have found a correlation between the initial roughness of sliding surfaces and their wear rate. Such correlations have been used to predict the failure time of contact surfaces. A section of standard length is sampled from the mean line on the roughness chart. The mean line is laid on a Cartesian coordinate system wherein the mean line runs in the direction of the x-axis and magnification is the y-axis. The value obtained with the formula on the right is expressed in micrometers (Om) when y=f(a).



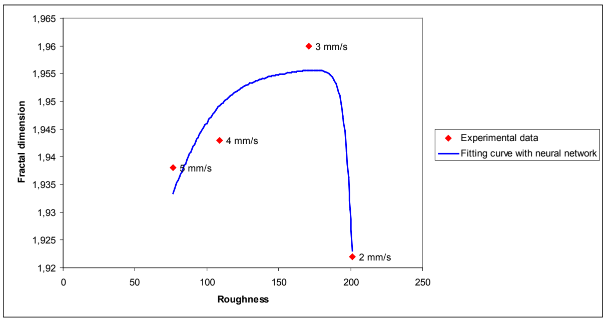
Graph 1. Arithmetical mean roughness (Ra)

3. RESULT

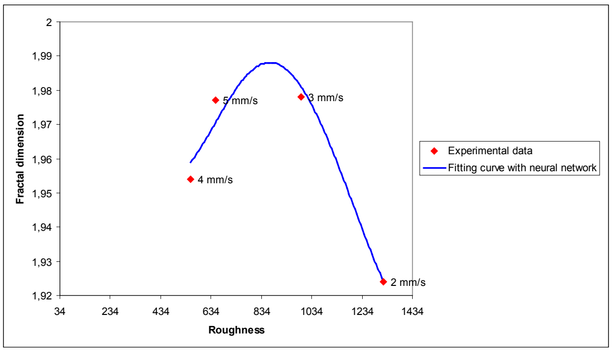
We studied the relationship between the fractal dimension, parameters of the robot laser cell and roughness (friction).



Graph 2. Roughness od robot laser hardenend specimens



Graph 3. Relationship between fractal dimension and roughness R_a in specimens hardened at different speeds at 1000 °C



Graph 4. Relationship between fractal dimension and roughness R_a in specimens hardened at different speeds at 1400 °C

4. CONCLUSION

The paper presents the use of fractal geometry to describe the mechanical properties of robot laser hardened specimens. We use a relatively new method, fractal geometry, to describe the complexity of laser hardened specimens. The main findings can be summarized as follows:

1. A fractal structure exists in the robot laser hardened specimens.
2. We describe the complexity of the robot laser hardened specimens using fractal geometry.
3. We have identified the optimal fractal dimension of tool steel hardened with different robot laser parameters.
4. We use the box-counting method to calculate the fractal dimension for robot laser hardened specimens with different parameters.

REFERENCES

[1] B.B. Mandelbrot. *The fractal geometry of Nature*. New York: W.H. Freeman, p. 93, 1982.

[2] P.V. Yasnii, P.O. Marushchak, I.V. Konovalenko, R.T. Bishchak, *Computer analysis of surface cracks in structural elements,* Materials Science 46, pp. 833-839, 2008.

[3] P.V. Yasnii, P.O. Marushchak, I.V. Konovalenko, R.T. Bishchak, *Structural degradation and damage caused by a system of cracks to the steel of metallurgical equipment,* Materials Science 47, pp. 798-803, 2009.

[4] C.C. Barton, Fractal Analysis of Scaling and Spatial Clustering of Fractures. In: Barton, C.C. and La Pointe, P.R. (eds.), F*ractals in the Earth Sciences*. Plenum Press. New York, pp. 141-178, 1995.

[5] L.W. Fan, Y.C. Hu, T. Tian, Z.T. Yu, *The predication of effective thermal conductivities perpendicular to the fibres of wood using a fractal model and an improved transient measurement technique*, International Journal of Heat Mass Transfer 49, pp. 4116–4123, 2006.

[6] T. Ficker, *Fractal strength of cement gels and universal dimension of fracture surfaces*, Theor. Appl. Fract. Mech. 50, pp. 167–171, 2008.

[7] M.Q. Jiang, J.X. Meng, J.B. Gao, X.L. Wang, T. Rouxel, V. Keryvin, Z. Ling, L.H. Dai, *Fractal in fracture of bulk metallic glass*, Intermetallics 18, pp. 2468–2471, 2010.

[8] A. Carpinteri, S.A. Puzzi, *A fractal approach to indentation size effect,* Engineering Fract. Mech. 73, pp. 2110-2122, 2006.