

# Roughness analysis of graphite surfaces of casting elements

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## Abstract

In the paper profilometric measurements of graphite casting elements were described. Basic topics necessary to assess roughness of their surfaces and influence of asperities on various properties related to manufacturing and use were discussed. Stylus profilometer technique of surface irregularities measurements including its limits resulting from pickup geometry and its contact with measured object were analyzed. Working principle of tactile profilometer and phenomena taking place during movement of a probe on a measured surface were shown. One of the important aspects is a flight phenomenon, which means movement of a pickup without contact with a surface during inspection resulting from too high scanning speed. Results of comparison research for graphite elements of new and used mould and pin composing a set were presented. Using some surface roughness, waviness and primary profile parameters (arithmetic mean of roughness profile heights Ra, biggest roughness profile height Rz, maximum primary profile height Pt as well as maximum waviness profile height Wt) a possibility of using surface asperities parameters as a measure of wear of chill graphite elements was proved. The most often applied parameter is Ra, but with a help of parameters from W and P family it was shown, that big changes occur not only for roughness but also for other components of surface irregularities.

**Keywords:** Quality Management, Product Development, Surface Roughness, Wear.

## 1. Introduction

From all geometrical metrology fields, measurements of surface asperities, in simplified form known as roughness measurements, are considered to be the most difficult and complex ones. Roughness is a natural state of surfaces, and left to its own devices, nature will make sure they are rough. The roughness of a surface is a measure of its lack of order. Disorder is the same what we understand as entropy and if one considers a solid surface as a closed system then the second law of thermodynamics predicts that its entropy will tend to a maximum [1]. To reduce roughness it is than necessary to reduce entropy, and doing that requires work, which in mechanical engineering is machining. We believe, that real roughness is so complicated, that at present its determination is not possible, and we can only describe assumed rough-

ness. Surfaces that we deal with in technical applications are very complex and asperities on them are featured with a wide range of height and length spectrum, distributed in various way all over the area. Facing still more and more sophisticated requirements regarding machines and machined workpieces, it becomes clear that crucial is not only fulfilling dimensional tolerances, but also including surface. Every machined workpiece has some deviations in relation to its perfect nominal shape. Irregularities can cover even up to 50% of tolerance field defined by construction requirements, particularly in case of connection with very narrow tolerances. Principally, the less is surface roughness, the more expensive is its manufacturing. Surface metrology is a science regarding deviations of real workpiece in relation to a nominal one (from documentation), comprising form, waviness and roughness deviations composing together a geometrical structure of a surface.

Surface topography (i.e. asperities in three dimensional meaning) plays a fundamental role having a decisive influence on basic tribological properties of surface, as well as sealing, fatigue, thermal and electrical conductivity, friction, deflection and also esthetic features. Surface asperities are also one of the factor of choosing proper manufacturing process. Hence, still more and more often manufactured items have surfaces created with geometrical structures for very specific needs, and analysis of irregularities on them is at least as important an dimensional analysis. In industry applications casting roughness assessment is based on visual inspection or comparison with roughness comparison specimens [2]. With more advanced applications measuring (also including profilometric methods) becomes necessary. Regarding asperities analysis in casting applications, in references one can find sources with surface roughness description of coal cast steel after continuous casting [3] and research regarding influence of coal and chromium on surface roughness of cast steel rollers after centrifugal casting [4].

## 2. Measurements of surface asperities

The most popular way of surface roughness analysis is tactile profilometry. Here, pickup with a diamond tip is moved over a surface at a defined distance with approximately constant speed. On figure 1 a scheme of typical profilometer is presented.

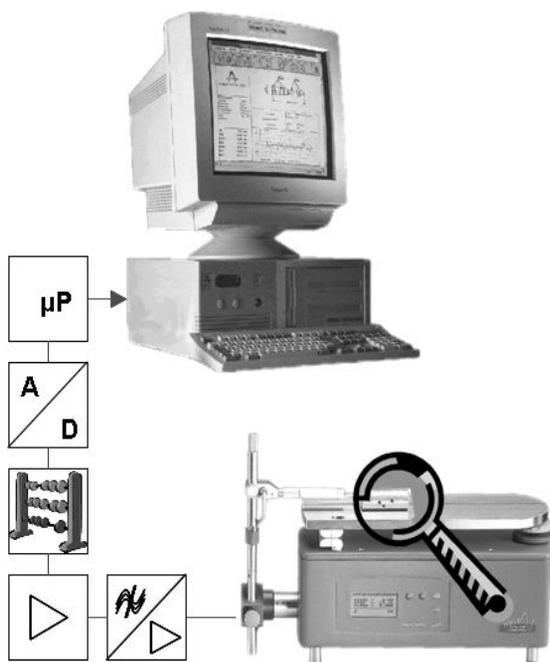


Fig. 1. Scheme of a typical profilometer

The device can be separated into mechanical setup (including a pickup) and electronics (for control, data collecting and presentation of results). Vertical resolution in profilometric methods starts from single nanometers or even their fractions, while range can reach several millimeters. The idea of measurement via tactile method comes from gramophone working principle, where sharp needle moves over a surface of a record converting its asperities

into a different kind of energy, resulting in sound from loudspeakers as a final effect.

It is very important in tactile measurements, that real topography of a surface can be misinterpreted because of tip dimensions [5] its kinematic behaviour and load, to say nothing about electrical filtration of signal as well as conversion process errors - digitization, quantization and sampling [6]. Geometry, load and scanning speed of a tip representing asperities of a measured surface have influence on results correctness. The tip itself moving over a profile acts as a mechanical filter. More important is here its radius than a vertex angle. With a bigger radius area which cannot be penetrated by a tip increases. An example of influence of tip radius on form of represented profile was shown on figure 2 [7].



Fig. 2. An outlook of profile measured with different tip radii: 1 - solid line shows pickup with 10  $\mu m$  radius, 2 - short segmented line stands for pickup with 5  $\mu m$  radius, 3 - line with segments and points stands for pickup with 2  $\mu m$  radius.

A problem is here not only tip curvature but also its local changes. Shape of typical probe tip was presented on fig. 3, and its image after damage on fig. 4.

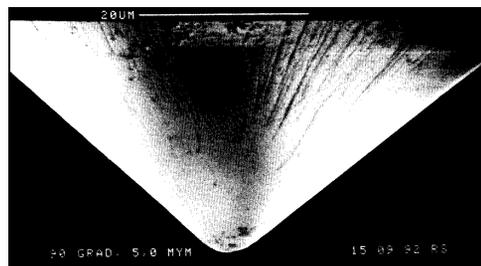


Fig. 3. Shape of a profilometer tip vertex

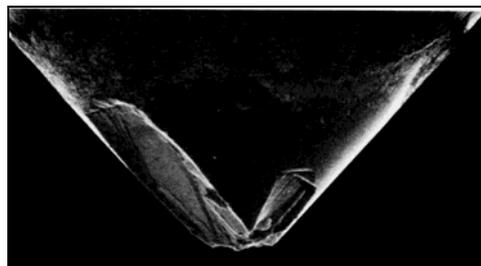


Fig. 4. Shape of a damaged profilometer tip vertex

Tip damages generally lead to increase of radius (flattening of vertex) and further to detecting values smaller than they really appear. Tactile probe (pickup) has then averaging filtering action, basing on not penetrating of narrow gaps or irregularities with scale smaller than tip radius.

An important issue while roughness measuring is also load of pickup. It is particularly important when workpieces to be measured are made of soft materials and surface can be scratched by a diamond tip of a profilometer.

A potential reason of errors in profilometric surface analysis is also velocity of scanning with a tactile pickup. Movement takes place with certain speed, which - if will be big enough - can cause loose of contact between tip and surface (fig. 5). Errors resulting from that are an interesting topic for investigations also because while topographical multiprofilometry is considered a tendency to speed up measurement arises.

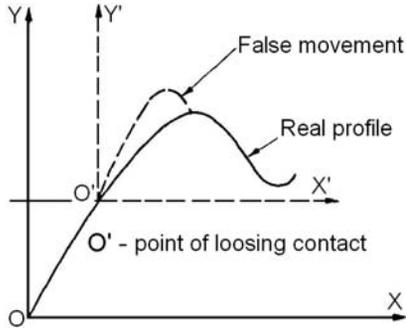


Fig. 5. Movement of a pickup after losing contact with surface [8]

Most of devices used nowadays for surface roughness measurements collect data basing on digital conversion of analogue data. Contemporary software makes it possible to measure more than 300 parameters regarding profile asperities and about 50 connected with topography (in 3D meaning). Irregularities can be analysed using different filters, sampling distances and grids, including a spiral one [9]. They can also be measured on lengths of even 200 millimeters with 100 mm widths maintaining guiding errors on the level of fraction of micrometer, with further option of using CAA systems (Computer Aided Accuracy). Guideways is than measured with laser interferometer and its errors are recorded in memory and used for corrections.

Raw coordinates of points measured along a profile collected from a surface and levelled compose a primary profile P, from which two components are derived: longwave component creating a waviness profile and a shortwave component being a roughness profile respectively.

### 3. Results and discussion

During use of chill, because of casting process and extracting elements from mould, roughness of graphite parts gets worse. Starting from initial value of Ra parameter less than  $0,32 \mu\text{m}$  wear causes its gradual increase up to about  $2 \mu\text{m}$ . Above this value height of asperities grow more rapidly reaching even as much as  $5 \mu\text{m}$ . This in turn causes a dramatical drop of castings quality and makes it more difficult to remove castings from mould.

Research on asperities was performed using chill elements made of graphite (mould and pin) used in manufacturing. Inspected moulds and pins were of two kinds: brand new ones and used, in status of rejecting from production. The outlook of these elements was presented on fig. 6. They are used to manufacture bronze rods, from which connecting elements are made. It is

worth mentioning that mould and pin surfaces that were measured in research create surfaces of cast elements that are not machined later, and hence casting quality is so important.

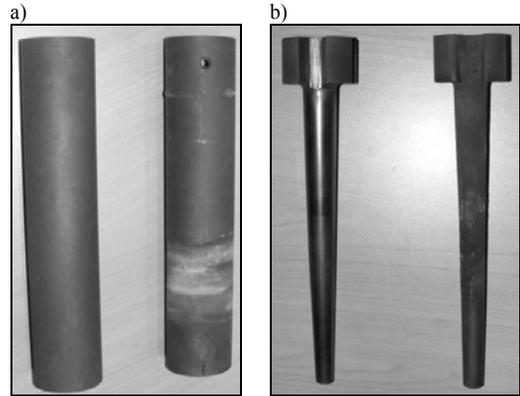


Fig. 6. New and used mould (a) as well as new and used pin (b)

Analysis was performed using tactile profilometer Hommel Etamic T8000 (fig. 7). Measurement setup consists of mechanical part (granite plate, column with tilting option, drive unit mounted on column and pickup) and electronic unit, used for control and computing proces.

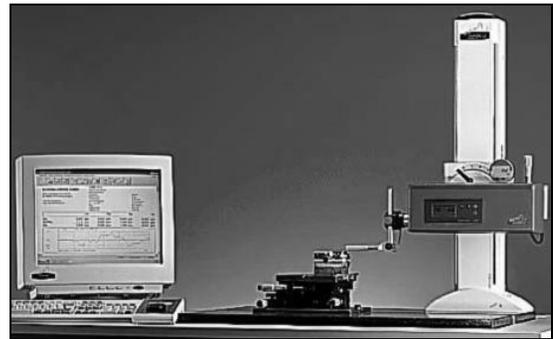


Fig. 7. Laboratory profilometer used in research [10]

Measurements were taken along the elements, on inner surfaces of moulds and on outer surfaces of pins. Figure 8 presents a scheme showing direction of measurements.

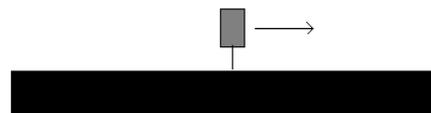


Fig. 8. Roughness measurement along pin

From every surface data were collected in five places and later average values of selected surface asperities parameters were calculated. In research, the following parameters were analyzed: Ra (arithmetical mean of roughness profile heights calculated from all vertical coordinates), Rz (biggest roughness profile height calculated as average of five highest and five lowest profile points according to ISO - each of them on separate cut-off), Pt

(maximum primary profile height - vertical difference between highest and lowest primary profile point) and Wt (maximum waviness profile height - vertical difference between highest and lowest waviness profile point). The results of this research are presented in table 1.

Table 1. Surface asperities parameters measured in research

Parameters	Element			
	Used mould	New mould	Used pin	New pin
Ra	2,92	0,23	4,07	0,12
Rz	16,41	1,61	20,80	1,16
Pt	31,79	3,11	66,34	2,36
Wt	10,60	0,89	43,35	0,55

The results show that values of all the inspected parameters for new elements are significantly smaller than for used work-

pieces. Ra parameter value is from 12 to more than 30 times smaller for new elements, while Rz value is 10 to 18 times smaller respectively. Pt during use of mould increases nearly 30 times for pin and 10 times for inner surface of mould. Waviness also changes dramatically - for pin even nearly 80 times. Profiles regarding all the described elements are shown on figures 9 - 12. Parameters values as well as profiles shown significant changes that occur on surfaces of graphite elements during their use while manufacturing bronze rods. All the components of asperities grow a lot and the surface loses its smoothness very fast. That in turn causes decrease of surface quality of castings. The process of surface asperities increase on graphite elements of mould is continuous and takes place from the beginning of its use until these elements have to be rejected from production.

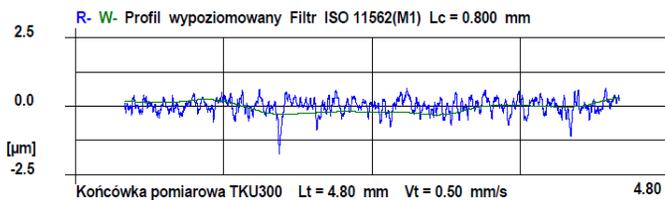


Fig.9. Roughness and waviness profiles of a new mould

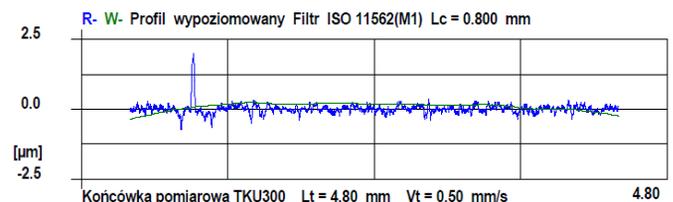


Fig.11. Roughness and waviness profiles of a new pin

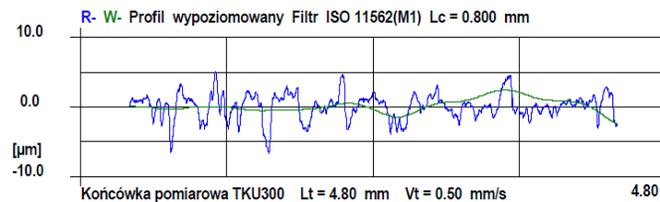


Fig.10. Roughness and waviness profiles of a used mould

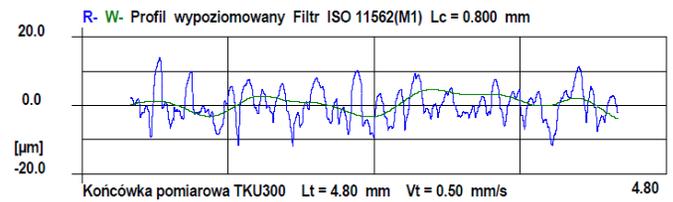


Fig.12. Roughness and waviness profiles of a used pin

## 4. Conclusions

In the paper use of surface asperities measurements to assess wear of graphite elements was presented. During use, roughness, waviness and primary profile of chill loose their smoothness. It results in the end in unacceptable quality of obtained surfaces, and furthermore (as surface gets more and more rough) also in more difficult removing of workpieces what in turn causes further damages in graphite structure.

Tactile profilometry proved to be a good tool for inspection of graphite surfaces. It is important, as this material is apt to scratching and tip of pickup is made of diamond what potentially can be hazardous to measured surfaces. Visual inspection after measurements show no visible damages made by tip load.

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