# COMBINED OF THE CLSM-SEM TECHNIQUES FOR MEASUREMENT AND ANALYSIS OF THE SINGLE GRAIN CUTTING SCRATCH ON INCOLOY® ALLOY 800HT®

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**Abstract**:

Knowledge and understanding of modern machining processes often requires the use of advanced microscopy techniques, such as, among others confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM). This work focused on the application of these microscopic techniques for measuring and analyzing of traces made by single abrasive grain cut, formed on the internal cylindrical surface of the sample made of INCOLOY® alloy 800HT®. The work was divided into two parts. In the first one, the most important types of materials machinability and grindability tests were briefly characterized, with particular reference to issues related with the testing of hard-to-cut materials. The most important properties of the sample as well as the methodology and equipment used in the experimental tests were also described. The second part contains a description of used microscopic techniques and presents selected results of measurements and analyses carried out on the trace shaped by single abrasive grain of microcrystalline sintered corundum SG™. All results presented in this part were obtained using a 3D laser microscope LEXT OLS4000 by Olympus and electron microscope JSM-5500LV by JEOL with dispersive spectrometer module INCAPentaFET-x3 with Si(Li) detector by Oxford Instruments. The results were compared with reference measurements obtained using a opto-digital microscope DSX500 by Olympus.

**Keywords**: Confocal laser scanning microscopy, Scanning electron microscopy, Scratch test, Hard-to-cut materials

## 1. INTRODUCTION

Abrasive machining is used in modern automated production processes in order to obtain precisely shaped surfaces with relatively low unevenness height and pre-determined strains' condition in the surface layer [1]. The course and the results of the grinding processes are largely dependent on the grinding wheel cutting ability, defined as the tool's predisposition to removing the machined material in the process of microcutting by randomly oriented abrasive grain apexes that come into contact with the machined material. In this context the randomness of the machined surface shaping process resulting from machining with geometrically non-identified blades is essential. The conditions in the zone of contact of the grinding wheel and the machined material are influenced by a number of factors, such as: the grinding wheel features, process kinematics and parameters, the type, removal rate and method of application of the cooling liquid, the type of machined material, and others [2-4].

In order to determine the elementary phenomena dominant in the microcutting process, the so-called *scratch tests* are used that allow to estimate susceptibility to grinding (grindability) of the machined material using the given abrasive grain type.

The assessment and analysis of the workpiece surface after performing *scratch tests* may be carried out using numerous methods, including advanced microscopic techniques [5, 6]. Support by dedicated image processing and analysis software, may give a number of possibilities available only in these techniques.

## 2. GRINDABILITY TESTS

Methods related to evaluation of single abrasive grains are usually used in assessment of phenomena that occur in the grinding zone. They consist in analysis of results of tests in cutting with a single grain [7, 8]. Such a grain is purpose-oriented and mounted in a metal casing (usually using soldering), which later on creates the scratches on the workpiece material by moving the grain along the flat surface of the measurement sample. Such methods are mostly based on evaluation of the removed material volume and the abrasive grain mass loss, registering the cutting forces and visual analyses of the cutting marks, forms of grains wear, chip shapes or the mechanism of flash creation. However, the traditional methods of evaluating the abrasive grains cutting ability do not take into consideration the specific kinematics of various grinding process types or the grinding dynamics in the given kinematics. This refers mostly to kinematics of internal cylindrical grinding process, in which there is a combination of grinding wheel rotational speed $n_s$ and (usually contra-rotating) motion of the workpiece with $n_w$ speed.

Thereupon, a different kinematic system of the single microcrystalline sintered corundum grain cutting ability test was used in the described examinations. What was observed in it was the kinematics occurring in the internal cylindrical grinding process.

## 3. TEST METHODOLOGY

The tests were carried out using a special measurement sleeve composed of a body and dismountable element which formed part of its perimeter, of rectangular shape with rounded tips, attached to the body with screws. The thus shaped measurement sample made it possible to carry out the microcutting process in internal cylindrical grinding process. Moreover, it facilitates performing tests with machining parameters similar to the ones used in industrial conditions. The dismountable sleeve element makes it possible to carry out measurements and analyses of the internal surface condition after microcutting process. Fig. 1 presents a diagram of kinematics of the realized tests.

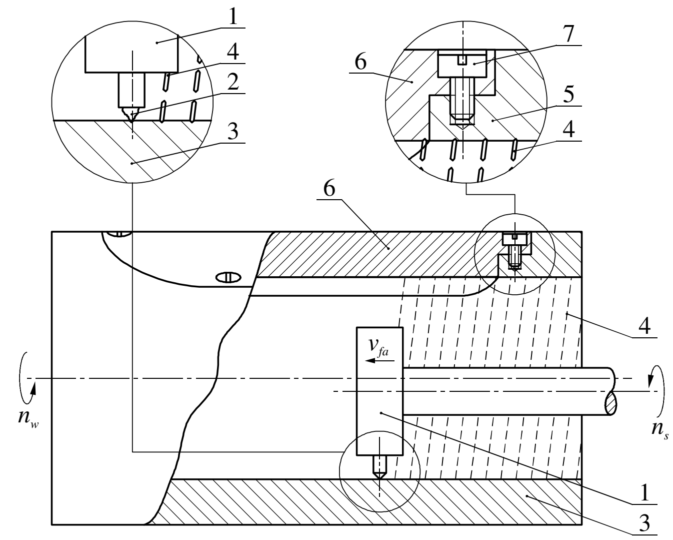


Fig. 1: Kinematics of microcutting test (1 – disc mounting abrasive grain, 2 – abrasive grain, 3 – measuring sample, 4 – scratch formed by grain, 5 – body of measuring sample, 6 – component of measuring sample, 7 – clamping screws, 8 – opening in the measuring sample)

### *3.1 Experimental setup*

The test were conducted using experimental setup build on the basis of universal grinding machine RUP 28P by Mechanical Works Tarnow SA (Poland), equipped with spindle type EV-70/70-2WB produced by Fisher (Switzerland) – max. rpm 60 000 1/min, power of machine cutting 5.2 kW.

### *3.2 Test conditions*

Table 1 presents in a synthetic way the most important conditions of experimental tests.

Table 1: General characteristics of grinding conditions.

| | |
|---|---|
| Process | Internal cylindrical grinding |
| Grinding machine | Universal grinding machine RUP 28P, Mechanical Works Tarnow SA (Poland) |
| Grinding parameters | $v_s$ = 30 m/s, $v_w$ = 0.75 m/s, $v_{fa}$ = 50.0 mm/s, $a_e$ = 0.02 mm |
| Abrasive grain | Microcrystalline sintered corundum grain SG™ (fracture No. 46), Norton (USA) |
| Coolant | Tests were conducted without coolant |
| Workpiece | Internal cylindrical surface of sleeve made of INCOLOY® alloy 800HT®, internal diameter: $d_w$ = 55 mm, width: $b_w$ = 100 mm |

($a_e$ – machining allowance; $v_s$ – grinding wheel peripheral speed; $v_w$ – workpiece peripheral speed; $v_{fa}$ – axial table feed speed).

### *3.3 Characteristics of workpiece material*

The tests was carry out using sleeve made of INCOLOY® alloy 800HT® (characteristics are given in Tab. 2).

Table 2: The characteristics of INCOLOY® alloy 800HT®.

| Name | Material No. | Standard | Chemical composition [%] |
|---|---|---|---|
| INCOLOY® alloy 800HT®* | 1.4876 | UNS N08811 ASTM B407 | Ni(30.0-35.0) Fe(39.5 min) Cr(19.0-23.0) C(0.10 max) Al(0.10.60) Ti(0.15-0.60) Mn(1.50 max) Cu(0.75 max) S(0.015 max) Si(1.0 max) |

INCOLOY® is a trademark of Special Metals Corporation (USA). Material is produced by Special Metals Corporation (USA) and distributed by Bibus Metals (Switzerland).

### *3.3 Measurement systems*

In the experimental tests were used 3 different advanced microscopy techniques presented in the Tab. 3.

Table 3: Measurement systems used in the experiments.

| No. | Designation | Producer | Measurement system |
|---|---|---|---|
| 1 | LEXT OLS4000 | Olympus (Japan) | CLSM |
| 2 | JSM-5500LV | JEOL (Japan) | SEM |
| 3 | INCAPenta FET-x3 | Oxford Instruments (UK) | EDS module |
| 4 | DSX500 | Olympus (Japan) | ODM |

CLSM – Confocal Laser Scanning Microscope, SEM – Scanning Electron Microscope, EDS – Energy Dispersive X-ray Spectroscopy, ODM – Opto-Digital Microscope

## 4. TEST RESULTS

A single abrasive grain contact mark, which occurred in the preliminary stage of the microcutting process, was selected for analysis from the obtained results group.

Fig. 2 presents a group of analyses of the microtopography of the obtained scratch’s surface registered using CLSM LEXT OLS4000by Olympus [9]. The input image (Fig. 2a-b) was microtopography of a relatively large workpiece surface fragment, sized 8.44×1.77 mm, that contained the well visible abrasive grain mark, which was located in its center. This image was obtained using the *image mapping* procedure. It consists in proper adjustment and combination of numerous small-sized surface topographies into a single resulting image. One of the greatest advantages of obtaining topography of such a large surface image is the possibility to determine the characteristic features of the scratch resulting from the contact of the abrasive grain and the machined material. The global geometry layout may form a starting point to considerably more detailed analyses of its fragments. This may further form the basis for precise determination of, among others, depth of the generated micropits and size of the side flashes in numerous cross-sections along the visible scratch (Fig. 2f-h).

The measurements of the microtopography of the shaped scratch’s surface were supplemented with observations using SEM JSM-5500LV by JEOL [10] (Fig. 3a-b).

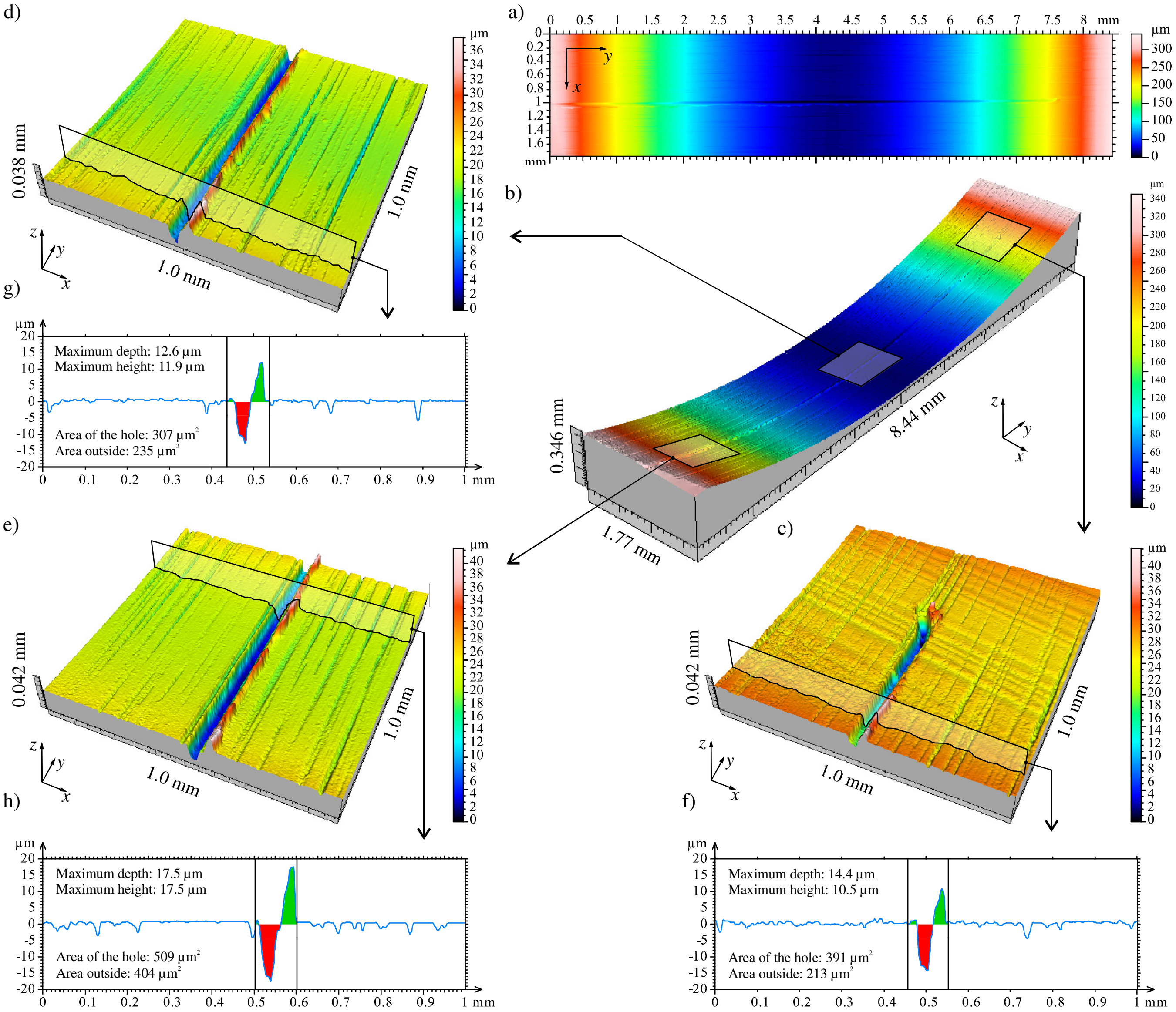


Fig. 2: of surface microtopographies measurements (a, b, c, d, e) and selected surface roughness profiles (f, g, h) obtained for workpiece after *scratch-test* using LEXT OLS4000 by Olympus

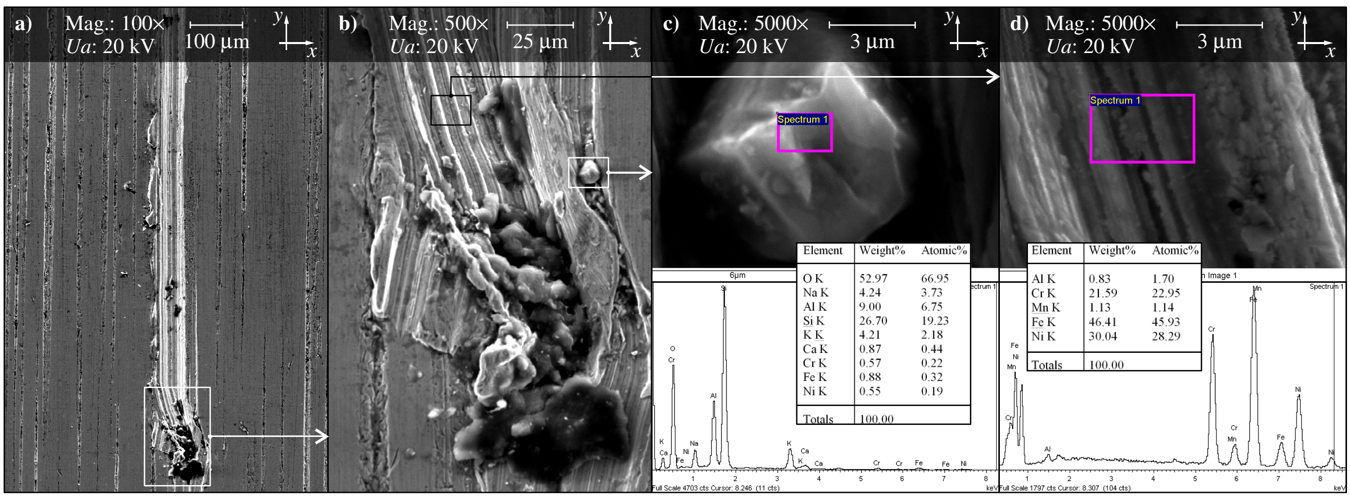


Fig. 3: SEM Results of image acquisition obtained for workpiece after *scratch-test* using JSM-5500LV by JEOL supported with INCAPentaFET-x3 by Oxford Instruments: a) SEM micrograph (mag. 100×); b) SEM micrograph (mag. 500×); c) EDS analysis of abrasive grain particle found on the surface workpiece; d) EDS analysis of microcutting trace

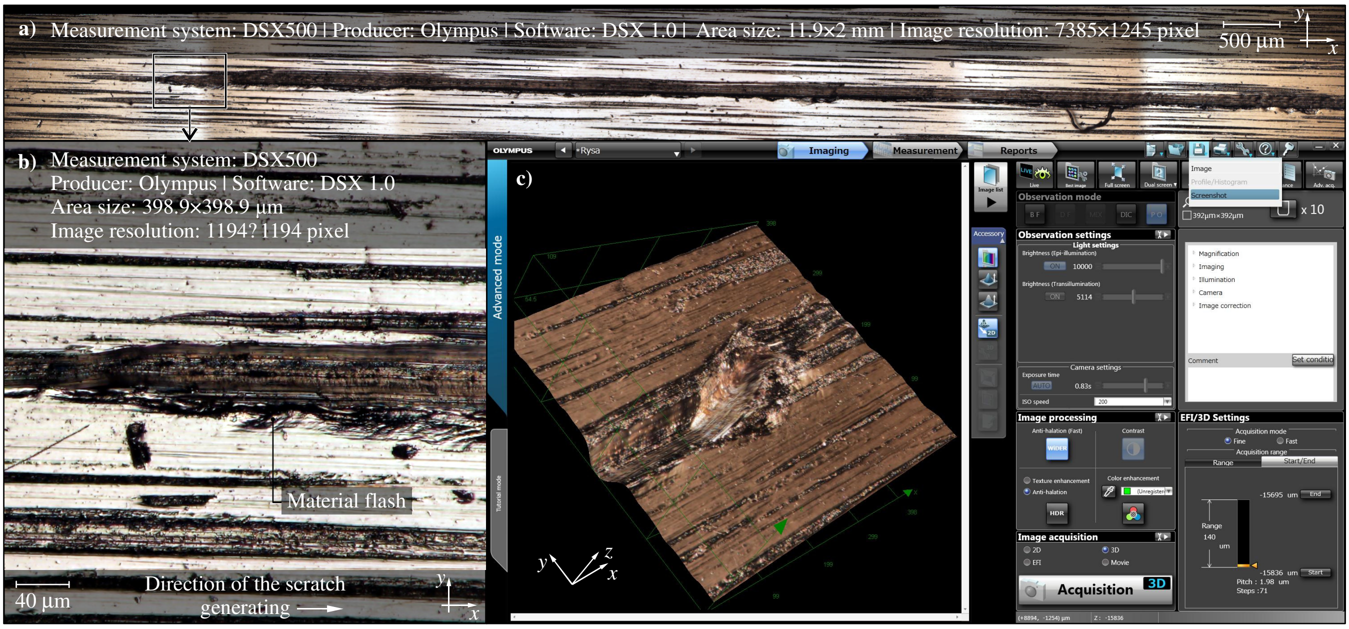


Fig. 4: Results of image acquisition obtained for workpiece after *scratch-test* using DSX 500 by Olympus: a) image presents general view of the scratch (area size: 11.9×2 mm); b) extracted fragment from previous image (area size 398.9×398.9 µm); c) screen shot of the DSX 1.0 software window during 3D visualization of selected fragment of tested workpiece surface (area size: 398.9×398.9×109 µm)

The microscope was equipped with an EDS INCA Penta FET-x3 module by Oxford Instruments, which was used for analyzing the element composition of selected fragments of the observed surface (Fig. 3c-d). The obtained analysis results allowed for identification of the chipped microcrystalline sintered corundum grain fragment which remained in place after contact with the machined material (Fig. 3c).

Moreover, an opto-digital DSX500 microscope produced by Olympus was used for analyzing the microcutting scratch (Fig. 4). The obtained measurement results allowed for visual analysis of the contact mark of the abrasive grain and the measurement sample, especially of the way the chip was formed, the flashes were shaped and ridging on basis of the images obtained in real colors.

## 5. CONCLUSIONS

The hereby thesis presents the application of advanced microscopic techniques (CLSM, SEM, ODM) in assessment of the cutting mark obtained in the process of microcutting with a single abrasive grain in the internal cylindrical grinding process kinematics. Application of the above-mentioned techniques allowed for obtaining a large amount of interesting measurement data. Their precise analysis exceeds the scope of this work and should be therefore treated as an indication of the possibilities of the applied measurement systems. Nevertheless, it should be stated that obtaining a vast spectrum of data from various instruments makes it possible to carry out complex multicriterion analyses of quantitative and qualitative nature. As a result, selected features of the analyzed surfaces can be more fully characterized. This is conducive to expanding the knowledge on phenomena and mechanisms that accompany the process of surface and technical objects (machine parts, elements of medical devices and measurement instruments).

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