

SEM and AFM Investigations of Surface Defects and Tool Wear of Multilayers Coated Carbide Inserts

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Abstract—Coated tool inserts can be considered as the backbone of machining processes due to their wear and heat resistance. However, defects of coating can degrade the integrity of these inserts and the number of these defects should be minimized or eliminated if possible. Recently, the advancement of coating processes and analytical tools open a new era for optimizing the coating tools. First, an overview is given regarding coating technology for cutting tool inserts. Testing techniques for coating layers properties, as well as the various coating defects and their assessment are also surveyed. Second, it is introduced an experimental approach to examine the possible coating defects and flaws of worn multicoated carbide inserts using two important techniques namely scanning electron microscopy and atomic force microscopy. Finally, it is recommended a simple procedure for investigating manufacturing defects and flaws of worn inserts.

Keywords—AFM, Coated inserts, Defects, SEM.

I. INTRODUCTION

APPLYING a thin coating layer(s) of carbides, nitrides, ceramic alloys, cermets, or metastable materials such as diamond and cubic boron nitride to the original material is critical to improve wear rate and to prevent the occurrence of catastrophic unexpected failure especially if it is used in hostile environments where high heat and friction exists [1]-[3]. Thin coating layers are conventionally deposited by various processes such as chemical vapor deposition (CVD), physical vapor deposition (PVD), medium-temperature CVD and plasma-activated CVD. Other techniques that have been successfully used to prepare high quality thin film coatings include pulsed laser ablation (PLA), filtered cathodic vacuum arc (FCVA) deposition, magnetron sputtering, RF plasma assisted chemical vapor deposition (PACVD) and mass selected ion beam (MSIB) deposition. The integrated coated surface system usually consists of the substrate, the interface and the coating layer(s). Each of these components affects, individually and interactively with others the performance of the surface system under practical operating circumstances.

To assess the integrity of the coating, different tests can be applied. For example, nano-indentation [1] is one of the most common techniques used to assess the mechanical properties of thin coatings. The scratch techniques determine the adhesion strength and load bearing capacity, the interfacial fatigue testing measures the cyclic bond strength of the coating under dynamic loads (e.g., [4]). Wedge impression test is recently used by Begley et al. [5] for measuring interface toughness between films and substrates using numerical methods. Also, Agrawal and Raj [6] introduced a tensile cracking approach to evaluate both the cohesive strength of

the coating and the interfacial adhesion strength between the coating and the substrate.

Defects of the coated inserts can reduce the toughness of the coating and thereby lead to coating failures. Defects can be introduced as a result of improper coating process, preparation inaccuracy or even due to inappropriate shipping and handling procedures. One of the common defects in PVD coating is the macro-particles and craters that can be classified to: pinholes or craters, droplets, and partly covered droplets [7]. Defects in this form are due to droplets incorporated during film growth and the pinholes are generated as a result of debonding of macro-particles from the coating [8]-[10].

Researchers investigated different ways to overcome these defects. Some methods that have been proposed to overcome some of these defects such as the droplet problem include distributed discharge arc, steered arc or arc with magnetic field filter [11]. A shield between the cathode and the substrate to prevent droplet adhesion was proposed by Taki et al. [12]-[14]. A strong correlation between the defect densities of the magnetron sputtered a-C coatings and the growth condition during their deposition was found by Vetter et al [15]. Four main factors are believed to influence the defect density: (a) cleaning state of the chamber, (b) different starting temperatures before coating, (c) sputtering power, correlated directly with the growth rate and the substrate temperature, and (d) shielding of the substrates resulting in a decrease of the impingement rates of small particles at the growing surface generated during growth [1]. Different local coating properties, e.g., inhomogeneous stress state can be caused by the presence of macroparticles and pinholes. Filtering techniques to guide the plasma efficiently to the substrate and in the process reduce the macro-particle content as they were reviewed by Anders [16]. The effect of poisoning the cathode to reduce the macroparticles content and size in PVD TiN coatings was investigated by Harris et al. [17].

The defected coating in tool inserts when used in practice may lead to unexpected outcome causing ultimate disorder especially at the unmanned automated applications. In metal cutting and machining applications, this could be one of the variability encountered in the determination of the reliable tool life [18].

Coating defects can be assessed by different microscopic techniques such as optical microscope (OM), scanning electron microscopy (SEM) and/or Atomic Force microscopy (AFM). These microscopic techniques can be utilized to investigate the integrity of the coating before the use of the inserts. Also, they are used to evaluate the wear of the insert after manufacturing processes such as cutting or machining.

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Atomic Force Microscopy AFM uses a mechanical probe for generation of magnified three dimensions images of surfaces down to nanometer resolution. The AFM usually reveals much valuable information about surface topography with minimal or no damage to the sample. However, its capability is limited by tiny scanned area [19]-[21]. Whereas, SEM can produce very high-resolution images that include secondary and back scattered electron images of a sample surface, revealing details of several nanometers. Fractured or worn surfaces can be easily studied in SEM since it has a large depth of field yielding a characteristic three-dimensional appearance. Quantitative X-ray analysis, and X-ray mapping of can be also handy for chemical compositions analysis.

Recently, the advancement of coating processes and analytical tools open a new era for optimizing the coating tools [22]. Therefore, the aim of this paper is to provide an insight for the use of AFM and SEM in pre and after use examinations for the coated carbide inserts to assess the possible existence of defects, wear and deformation.

II. MATERIALS, AND EXPERIMENTAL PROCEDURE

Five as received different types of tool inserts are tested throughout the different stages of this study; two uncoated and three multilayer coated with a cemented carbide substrate (as shown in Figure 1). The uncoated types are Kennametal K68 and K21 carbide inserts with ISO application range: M10-20 K05-20 (ANSI Range: C3). It consists of a hard, low binder content, unalloyed grade WC/Co fine-grained grade. As claimed by manufacturer, grade K68 has excellent abrasion resistance for machining cast irons, austenitic stainless steels, non-ferrous metals, nonmetals and, it is recommended by manufacturer to be used as a general purpose grade for non-ferrous materials.

The specifications of each of the three coated inserts are given as follow: the first coated carbide insert to test is the Kennametal multicoated KC810 CVD coated carbide with ISO Range: P10-30 (ANSI Range: C6-C7). It consists of a multilayered coating over an alloyed carbide substrate. As recommended by manufacturer, it is used for general steel machining at low to moderate speeds. Another two types of coated carbide inserts are used in this study: Sandvik CVD multicoated GC415 and GC435. The CVD TiN-Al₂O₃-TiC multilayer GC415 coated inserts are intended for turning steel and cast iron (P05-30, K05-20, C6-8). Due to its high wear and plastic deformation resistance, it is recommended for high metal removal rates within a broad application range. The multilayer coated GC435 (1 μm TiN followed by 3 μm Al₂O₃ and finally a layer of 5 μm TiC over the sintered carbide substrate) is used for steel cutting (ISO P35 range) with decreasing rates of plastic deformation and growth of thermal and mechanical fatigue cracks. Inserts are of SPUN 12 03 12 (thickness = 3.18 mm & r=1.2 mm & l=12.7 mm, clearance angle =5-7 rake angle = 6).

To avoid possible testing scratches from SPM probe, a new sample is employed for any scan run.

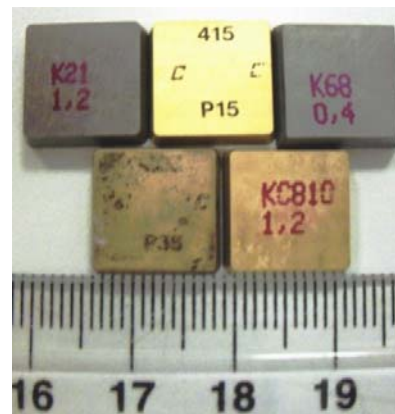


Fig.1 Types of some of the employed coated and uncoated carbide inserts

The NanoScope IV MultiMode Atomic force Microscope (AFM) Scanning Probe Microscope (SPM) in contact mode is used in this study. The contact mode is selected to suit the tribological nature and the object of the current study. The NanoScope™ software (NanoScope Software 6.13 User Guide, 2004) is used as a digital control of the AFM processes. Software features allow for all operations including preparation and manipulation of the microscope before, during and after scanning (offline analysis procedures).

To ensure system stability during scanning, a scan rate is set to be of 1.5—2.5 Hz. A scanner is of type AS-12 (E) with a max scan size of (12 \times 12 μm) and a vertical range up to 2.5 μm is selected throughout the entire study.

Two scanning electron microscopes were used in the analysis, they are:

1. JOEL JSM 5700 CarryScope with specifications (8x – 300000x up to 5.0 nm resolution, specimen size up to 150 mm in diameter and is attached with SmileShot™ software).
2. JOEL JSM 6300 attached with Energy Dispersive Spectroscopy (EDS) and Wavelength Dispersive Spectroscopy (WDS) for complete Quantitative and Qualitative Elemental X-Ray Microanalysis.

In addition to the possibility for surface pre-examination, SEM was used to get information regarding tool wear and deformation of the carbide coated and uncoated inserts.

II. RESULTS AND DISCUSSION

Generally, since SEM can provide a wider area for examinations than AFM, SEM investigations were first carried out for the unused multi-layers coated and uncoated carbide inserts to assess any manufacturing defects. Different defects were found in the unused carbide insert that include spallation, delamination and macro-particles of the coating. Different image magnification was taken to show the overall defected areas. For example, Figure 2 shows the spallation and delamination of coating in different magnifications. Agglomeration of coating particle was also present in some spots of the coated inserts.

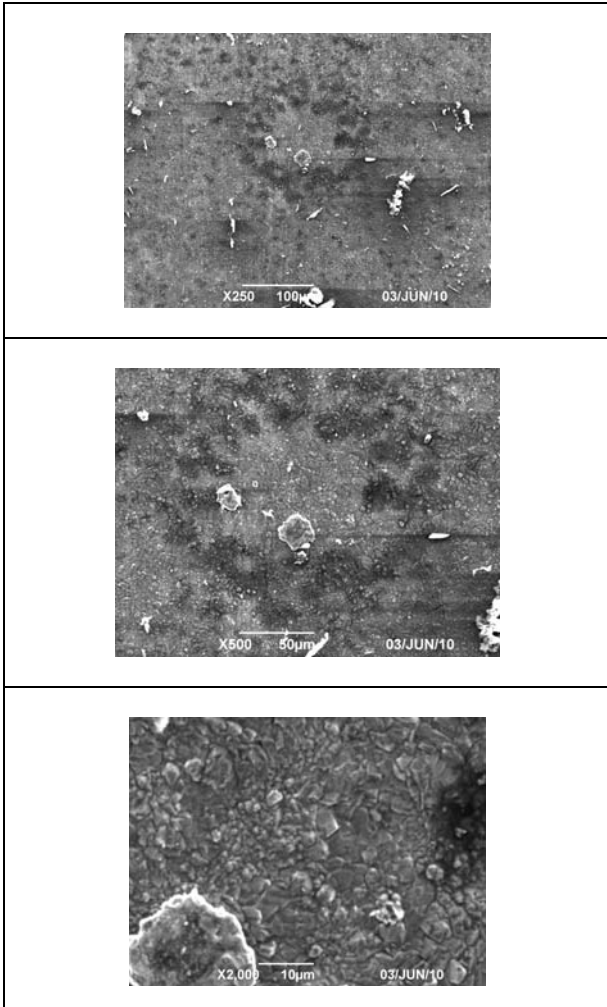


Fig. 2 SEM Surface examination of GC415 multilayers coated carbide inserts at different magnification (showing frequent coating spallation and delamination)

Macroparticle of coating is found in secondary electron image of multilayer coated sample as shown in Figure 3. AFM was then used to investigate the same area of the sample and it gave another set of beneficial data as shown in Figure 4. The quality of surface smoothness can be assessed from the data obtained. The software of AFM provides many topographical aspects including classical roughness values, peak and summit texture data and surface area calculations for the entire image. The roughness of the surface and a coating droplet were found.

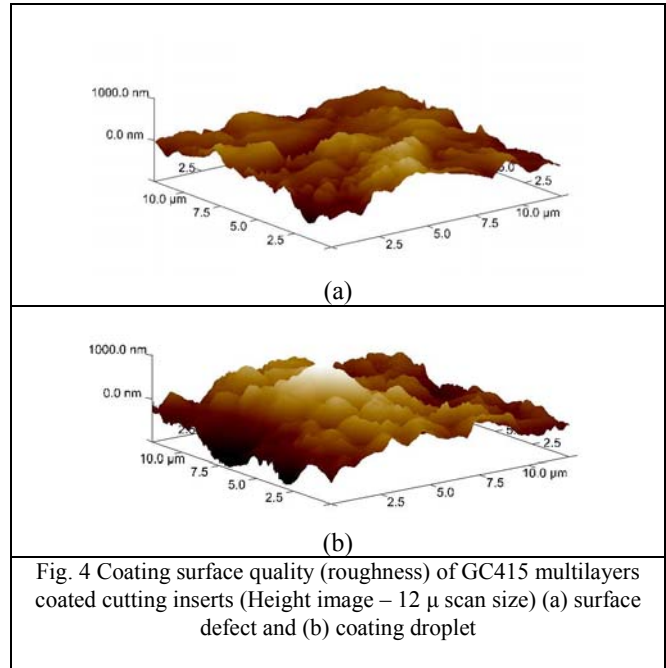


Fig. 4 Coating surface quality (roughness) of GC415 multilayers coated cutting inserts (Height image – 12 μ scan size) (a) surface defect and (b) coating droplet

The second stage was to investigate the worn inserts. The same procedure used early was used here namely starting with the SEM then AFM. Low magnification secondary electron images were taken for the flaws and defects of the worn surfaces. Different modes of tool wear and deformation such as edge chipping, fracture on the tool face, notch wear, nose deformation, crater wear and coating deformation are shown in Figure 5.

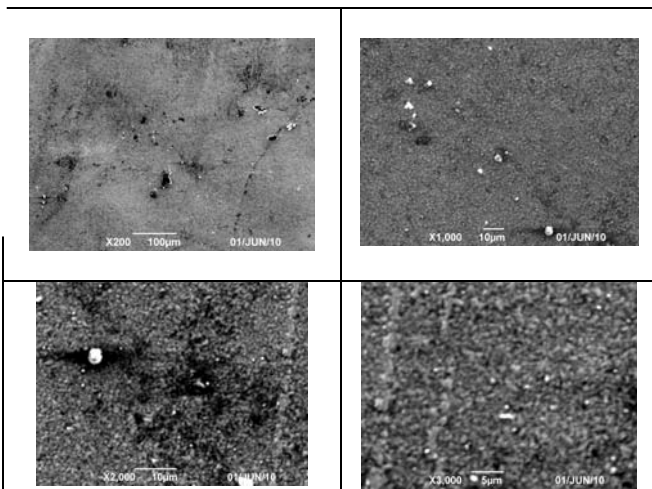


Fig. 3 SEM Surface examination of KC810 multilayers coated carbide inserts at different magnification (showing macroparticles of the coating)

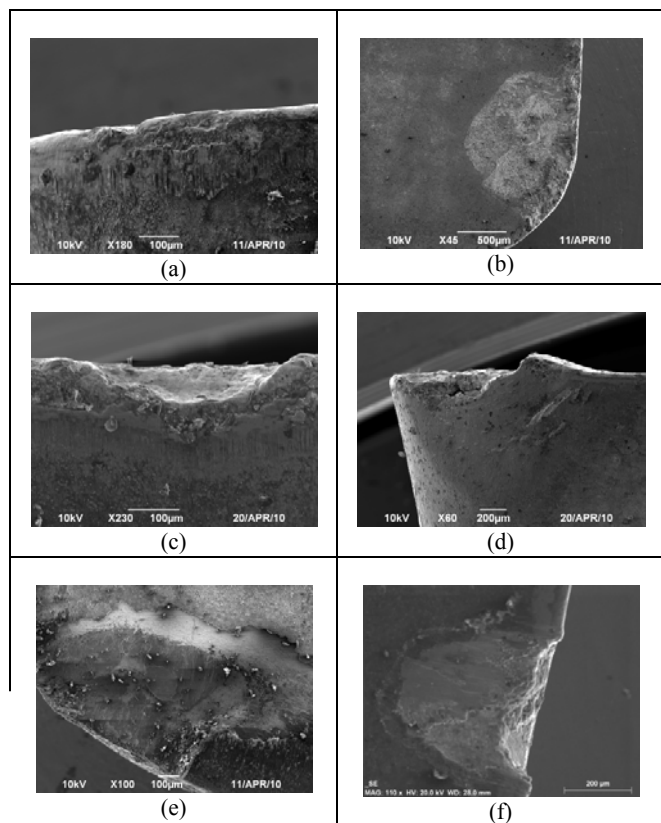


Fig. 5 SEM micrograph GC415 multilayers carbide inserts showing (a) edge chipping , (b) fracture on the tool face, (c) notch wear, (d) nose deformation, (e) crater wear and coating deformation and (f) wear on Notch-Flank intersection

The X-ray elemental mapping attached with SEM allows the user to investigate the elements present in the worn layers of mulilayers coating. This was carried out to assess the wear extent in each layer and it is shown in Figure 6.

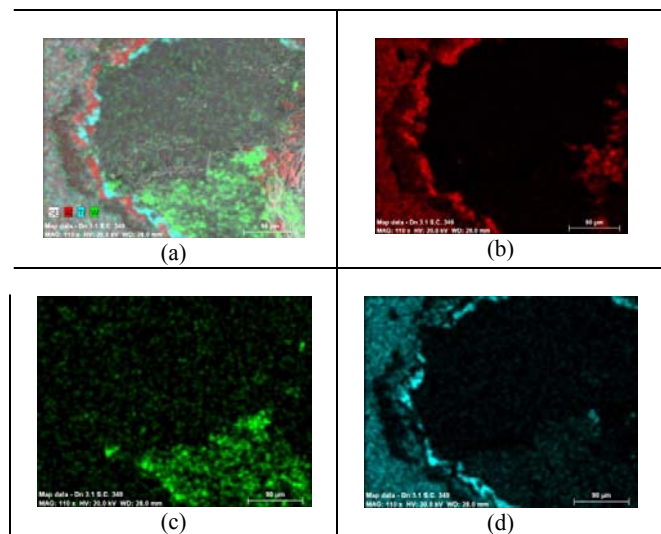


Fig. 6 X-ray elemental mapping of the wear on Notch-Flank intersection showing (a) All, (b) Al, (c) W and (d) Ti

EDS was also utilized to check the semi-quantitative chemical composition of certain areas and points. The second stage was to use the AFM in some worn area to measure the different topographical parameters such as horizontal, vertical and surface distances. Two 3D Height images are shown in Figure 7 below.

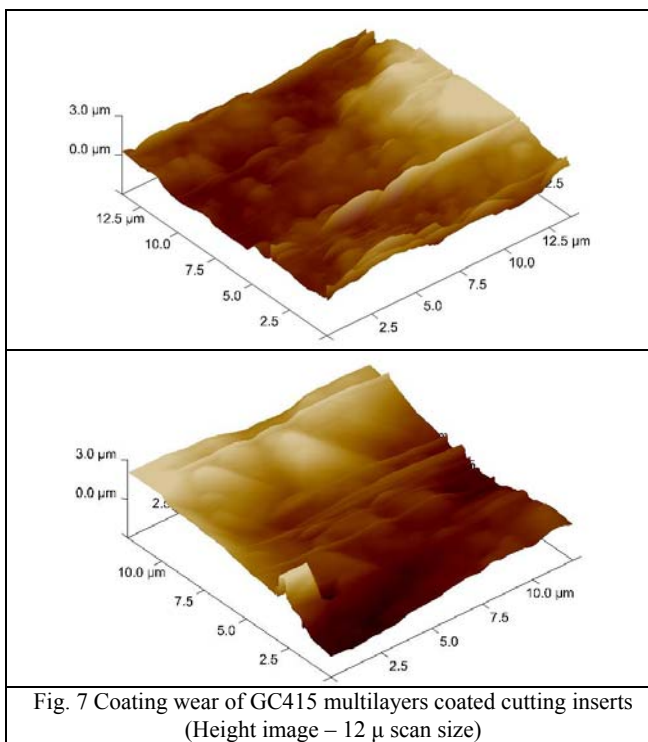


Fig. 7 Coating wear of GC415 multilayers coated cutting inserts (Height image – 12 µ scan size)

The combination of using both of SEM and AFM can provide essential information on defects and wear of multilayer coated inserts. Recent work has utilized friction force and dynamic force microscopy for measuring wear on the nano-scale [3]. The use of SEM can assist in choosing the right and exact area for investigation, whereas AFM can be used for topographical measurement of micro and nano scale. In this study, the use of SEM showed different types of defects and tool wear modes as shown in Fig. 2, 3, and 5. However, the presence of defects in the coated insert is not always critical. The advancement of analytical techniques allows the users to explore most of the coating defects. By utilizing these analytical tools, researchers can find out critical defects and their density limit by systematic study of unused inserts with different types and density of defects. A study that defines the critical defects and the density limit of them is valuable for machining specialists and industry. As a general rule, SEM should be used always first since it can capture a wider area for investigations. It also provides a semi-quantitative analysis of the chemical composition and elemental mapping of the area of interest. This allow to investigate the trace element resulted from the interaction of workpiece and worn inserts [23]. Subsequent to choosing the area of interest for investigation AFM can be utilized to find out the

topographical parameters desired. Non-contact mode AFM can be a valuable tool for evaluating the morphology and deposits on coating surfaces [24]. The use of SEM and AFM limit the artifacts that can be encountered using AFM separately. All in all, the use of both SEM and AFM has a high potential for assessing defects and wear modes for both coated and uncoated inserts.

IV. CONCLUSIONS

The paper investigated the various defects and wear modes of coated inserts. It showed the potential of SEM and AFM in investigating unused and worn carbide inserts surfaces. In order to optimize the information that can be obtained from SEM, it is proposed here to use a combination of SEM and AFM in the analysis. The combination use of SEM and AFM can provide essential information on defects and wear modes of multilayer coated inserts. This ensures the availability of simultaneous information about the surface topography in nano, micro and macro scales.

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