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Evaluation of the cutting tool wear rate using roughness and optical techniques

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Abstract: This study addresses the wear that occurs in cutting milling tools when they are operated for extended periods on various types of materials. The aim of this study is to measure the wear in these tools due to stress, high temperatures, and other factors such as aging, improper use, and unbalancing during operation. The methods employed include optical techniques using a digital microscope, which captures precise photos before and after use. The second method involves measuring the roughness of the surfaces of the cutting edges of these tools. It was found that the roughness values of the cutting edges vary after specific working hours; the roughness values decrease after operation. For carbide tools, the roughness decreased by 5%, while for HSS tools, it decreased by about 25% under the same operating conditions.
Keywords: *Cutting tools, Microstructure, Optical methods, Surface roughness, Wear.*

1. Introduction

The cutting tool wear is a natural phenomenon occurring while machining wood. The tool wear rate, dynamics of the wear progress and mechanisms of recession are very complex and depend on several factors such as; cutting angles, tool material, processed wood properties, machine dynamics, and processing speeds among others. Even if from practical point of view the cutting tool edge geometry is not such important as generated surface roughness, it is crucial for understanding of the wear physics. Consequently it is very important information for tool producers and researchers. Several methods have been applied for estimation of the tool wear. The goal of this work was however to design and verify novel optical instruments (such as laser micrometer and triangulation scanner) in scrutinizing of tool wear and scanning of the cutting tool geometry. Monitoring tool wear is very important in machining industry as it may result in loss of dimensional accuracy and quality of finished product. This work includes the development of machine vision system for the direct measurement of flank wear of carbide cutting tool inserts. This system consists of an optical system depends on shadow to compare the tool wear image, a good light source to illuminate the tool, and a computer may be used for image processing. The vision system extracts tool wear parameters such as average tool wear width, tool wear area, and tool wear perimeter. Wood and metal cutting is a complex process in which many phenomena interfere together. The cutting tool type and edge geometry, kinematic parameters of machining and material properties decide of machined surface geometry, cutting forces, energy consumption, vibrations, noise level and many others. Sharp cutting edge has a positive impact on widely understood machining quality and therefore it is crucial from industrial point of view to increase the life-span of tool (until it is still sharp enough to ensure quality demands). For this reason new, more wear-resistant coatings and bulk materials are introduced into tool production (e.g. Polycrystalline Diamond, Diamond Dispersed Cemented Carbides).

Measurement of tool wear is extremely important to predict the useful life of tool inserts. This will be helpful to monitor and to study the effects of the tool wear on quality of machined workpiece and

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economy of manufacturing process. There are two main methods to measure tool wear: indirect and direct methods. In the indirect method, tool wear is estimated with the signals coming from different types of sensors such as surface texture of machined workpiece, acoustics, vibration, feed forces, and current consumption [1-5]. The tool wear prediction model is prepared based on the magnitude of collected signals. Other method for the measurement of tool wear is the direct measurement over the tool wear zone. There are two main tool wear types: flank wear and crater wear. The flank wear is widely used to quantify the severity of tool wear. Characteristics of qualitative and quantitative morphology of tool wear are of great concern for researchers nowadays. More morphological features other than commonly considered parameter, i.e., average tool wear width, are required for better evaluation of the actual condition of tool which can affect machining process and quality of machined workpiece. The study shows that there is prominent effect of these new tool wear parameters on producing quality workpiece and also has an economic advantage by making strategies for timely changing tool inserts.

Tool wear generally results in loss in dimensional accuracy of finished products, possible damage to workpiece, and decrease in surface integrity and amplification of chatter. Detailed review for the tool condition monitoring indicates that the machine vision system can be extremely useful for the direct measurement of various types of tool wear [6]. Some statistical approaches are also useful in conjunction with machine vision system to find tool wear. Some researchers developed their own algorithm for the edge detection and segmentation of tool zone. White light interferometry and stereo vision technique are used for the measurement of volumetric wear in crater as well as flank wear region. Teti et al. presented detailed review of the sensor technologies, signal processing, and decision-making strategies for the efficient machining systems [7].

Various methods are suggested for the online and offline condition monitoring of the machining tool. Danesh and Khalili measured tool wear in terms of surface texture of the workpiece during the turning process using undecimated wavelet transform and statistical features of the surface irregularities [5]. Yu et al. used morphological component analysis and edge detection techniques to detect the wear edges under carrying working conditions [8]. D'Addona and Teti used artificial neural network for the automatic and real-time evaluation of the crater wear depth during quasi-orthogonal cutting tests on AISI 1045 steel using tungsten carbide insert D'Addona and Teti [9]. Xiong, et al. [10] developed an image processing algorithm using Matlab to measure the tool wear area. The image acquisition system consists of high-resolution CCD camera, fluorescent high-frequency linear lights, and data acquisition module [10]. Schmitt et al. developed an automatic tool wear monitoring system based on the active contour algorithm and neural networks for the flank wear measurement [11]. Fernández-Robles et al. developed an algorithm to measure the defects in cutting edges of milling inserts online without disturbing the machining operation. A three-stage algorithm consists of edge preserving smoothing filter, computation of image gradient, and assessment of damage of cutting edge using geometrical properties [12].

Some assumptions are also made to quantify the volume of wear region approximately. The wear at the tool nose was measured by assuming the part of cutting edge as a disk of radius equal to a tool nose radius [13]. Various geometrical parameters are determined for flank wear region by standardizing the wear region as an ellipse [2]. Researchers suggested various tool wear parameters such as maximum wear land width, wear land area, wear land perimeter [14] and compactness [3] length of major axis, length of minor axis, eccentricity, orientation, equivalent diameter, solidity and extent [2-4] end wear length [15] and nose radius and flank wear width [16].

Current work is focused on the measurement of flank wear using the machine vision system. A new approach of inline automatic calibration is proposed here. Average tool wear width, tool wear area, and tool wear perimeter are measured using the machine vision system. All these tool wear parameters are correlated with the machining time.

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2. Methodology

The optical 3D measurement device based on Focus-Variation, which is used for the measurements introduced in this article, is Infinite Focus by Alicona (Figure 1). In order to perform 3D measurements the device vertically scans the specimen by the sensor while continuously acquiring data. Since the system has a limited depth of field only small parts of the object are imaged sharply at the same time. By analyzing the variation of focus during the scanning process for each measurement a complete 3D model is obtained. A detailed description of the measurement principle can be found in [17].

In addition to the 3D data, the measurement device also delivers true color information for each measurement position, which is perfectly registered to the height data. This color information often enables the user to classify regions that have not been used, and those where wear has occurred. Additionally, a repeatability measure is analytically estimated for each measurement point. This repeatability measure is an estimation of the standard deviation of the z-coordinate of the measurement point as it would occur in a measurement series. This measure can be used for different investigations such as the estimation of the quality of the measurement points, the filtering of measurement points with bad repeatability, the detection of vibrations or other exterior influences during the measurement. In order to analyze the geometry of a cutting edge, a special software module is available that analyzes cutting edges on a surface profile-based basis. First profile paths are defined in the true color image of the cutting tool either automatically or manually. Then a height profile is extracted from a specified profile path (marked blue) and the resulting height diagram is visualized in region 2-Figure 2. This profile typically consists of two steep flanks and a rounded top region. In order to quantify the quality of the cutting edge a series of different parameters can be extracted as described in region 4 of Fig. 2. The most important parameter is the cutting-edge radius which is obtained by the following automatic procedure:

- Fit a straight line into the left and right surface flank of the cutting edge.
- Determine the top region of the edge by extracting those surface points where the deviation to the corresponding fitted line increases above a certain threshold.
- Fit a circle robustly into the segmented top region of the height profile.

The extracted parameters such as the edge radius or the angle between the fitted lines are then listed in the table in region 3 of Fig. 2. By switching between the different surface profiles, a good impression of the change of the height parameters across the edge is obtained. Another important parameter for the description of the quality of a tool is the roughness of the surface. This can be either calculated according to the draft of the ISO standard 25178 [ISO 25178-2, Draft] in an area-based matter or on a profile-based basis according to [ISO 4287, ISO 4288]. The knowledge of the surface roughness has a significant influence on the production since it influences among others how well the material can be chipped.

A third important parameter is the volume of the material that has been worn during the manufacturing process. This can be obtained using the following procedure:

1. 3D measurement of the tool before usage.
2. 3D measurement of the tool after usage.
3. Automatic registration of the 3D models to each other.
4. Calculation of the difference of the two 3D models.
5. Calculation of the volume of the difference model.

The automatic registration of the 3D models is necessary in order to assure that the difference is correctly calculated from corresponding points.

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Figure 1.
Infinite focus system.

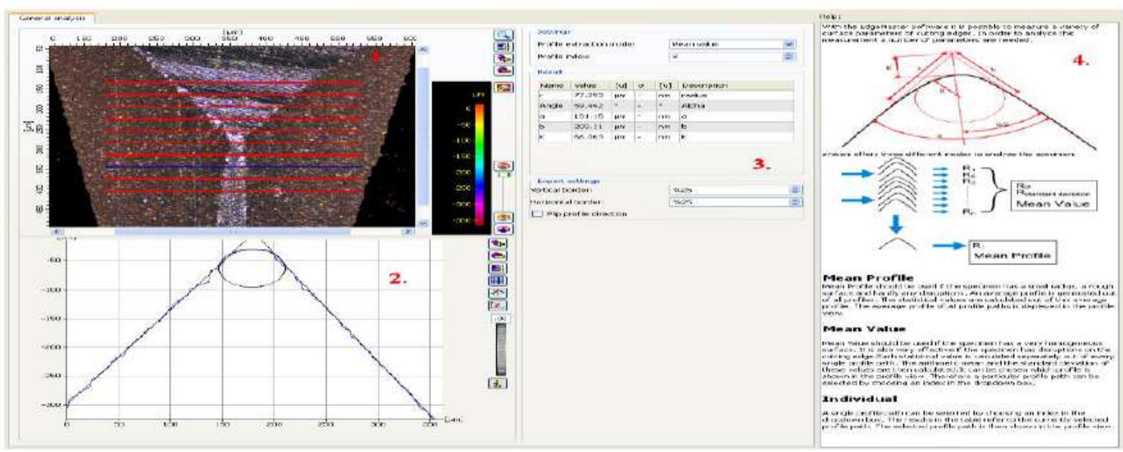

Figure 2.
Edge analysis profiles.

In order to judge the quality of cutting tools it is necessary to measure their geometry and wear during their use in the industrial process. This allows taking measures to improve the quality and durability of the tools as well as to increase the machining speed. Many researches discussed the wear in cutting tools. Danzl and Helmli [17] demonstrate how the 3D metrology device Infinite Focus can be used for such complex geometry and wear measurements. Due to its special technology it is able to measure even very steep surface slopes and delivers highly accurate 3D data together with perfectly registered true color information. They demonstrated the performance of the system by geometry measurements on different cutting tools with radii down to 3µm. By using special registration algorithms the system is able to compare the three-dimensional structure of the tools before and after their usage and to determine important parameters such as the total volume of worn and accumulated material.

Nebot, et al. [18] studied the portability problem, of how a proper surface roughness model obtained from theoretical/experimental data under specific conditions decreases its performance when it is applied in a different environment. The paper described and quantifies experimentally the portability problem of theoretical/empirical surface roughness models in face milling operations. In a first set of experiments the model error for R_a and R_z estimation was around 10%. However, when the cutting conditions applied are different from the ones used during the model building stage, the average model error increased to 30%. In this set of experiments, the change from dry cutting to flood coolant was observed to be non-significant and the performance of the models was adequate. Nevertheless, the change of workpiece material (a slight increase of hardness from 150 HB to 175 HB) makes the model to decrease its performance notably, making the model non-reliable. The situation gets worse when cutting-tool changes (slight change of cutting insert geometry, from 12 mm diameter to 10 mm diameter) or the machine-tool changes (from a CNC machine-tool center to a manual milling machine-tool). In both cases, the surface roughness models from previous cutting conditions are not valid and new surface roughness models would be required. This experimentation showed the critical effect of other factors besides cutting parameters on surface roughness which demonstrates the challenge of developing surface roughness models that can be applied in different scenarios. The research in generating robust models that can be adapted to different cutting conditions with a minimum experimental data should be studied in detail as future work. Čerče, et al. [19] presented an innovative, robust and reliable direct measurement procedure for measuring spatial cutting tool wear in-line, using a laser profile sensor. This technique allows for the determination of 3D wear profiles, which is an advantage over the currently used 2D subjective techniques (microscopes, etc.). The use of the proposed measurement system removes the need for manual inspection and minimizes the time used for wear measurement. In their paper, the system is experimentally tested on a case study, with further in-depth analyses of spatial cutting tool wear performed. In addition to tool wear measurements, tool wear modelling and tool life characterization are also performed. Based on this, a new tool life criterion is proposed, which includes the spatial characteristics of the measured tool wear. The results of this work showed that novel tool wear and tool life diagnostics yield an objective and robust methodology allowing tool wear progression to be tracked, without interruptions in the machining process or in the performance of the machining process. This work showed that such an automation of tool wear diagnostics, on a machine tool, can positively influence the productivity and quality of the machining process. Abd Halim, et al. [20] compared ultrasonic assisted milling (UAM) with conventional milling (CM) of CFRP in term of tool wear, cutting force, surface roughness, and machining temperature. Experiments for UAM and CM were conducted using three fluted polycrystalline-diamond (PCD) tools employing constant speed (500m/min) and feed rate (0.8m/min). For UAM, the amplitude and frequency were fixed at 5μm and 39000 Hz, respectively. Application of UAM resulted in reduced forces (up to 20 %) and temperatures (up to 15 %), however, it was observed that surface roughness increased (up to 5 %). In addition, UAM produced higher tool wear (106 μm) when compared to CM (80 μm) after 10m machining length. Analysis of thermal damage of machined surface using Different Scanning Calorimetry (DSC) is also presented. The glass transition temperature (Tg) of CFRP shifted from 272 °C to ≈70 °C for both UAM and CM suggesting that machining temperature resulted in significant material property changes. Palubicki, et al. [21] proposed a method depending on scanning of the cutting edge micro geometry in three dimensions and reproducing it in a virtual space as a 3D surface. The application of the method opens new possibilities of studying tool wear by scanning, including the calculation of volume loss and other analysis of tool wedge geometry along and perpendicularly to the cutting edge. Effectiveness of the method and scanner were successfully verified by a reference ESEM (Environmental Scanning Electron Microscopy) method.

3. Materials and Methods

This study deals with materials and methods used in measuring and testing samples wear by using both visual and roughness methods. The following sections describe tools, devices and apparatus used in the experiments. and also methods used.

3.1. Tools and Apparatus

Figure 3 shows the cutting tools used in this study. They are of two types: HSS and carbide tools.

Figure 3.
HSS and carbide cutting tools.

3.2. HSS Tools Properties and Specifications

In the existing steel, HSS is undoubtedly one of the most complex steel species because of the complex relationship between composition, organization and performance, and the difficulty of the whole manufacturing process including smelting, pouring, forging, rolling, plastic forming and heat treatment. For a long time, a lot of basic research and application practice have been performed on heat treatment process of HSS, which enriched the knowledge base of heat treatment process, and made an indelible contribution to rapid development of manufacturing industry in our country and occupation of the foreign tool market. Heat treatment of cutting tools has been paid more and more attention.

- The heat treatment of HSS cutting tools have many characteristics.

(1) The morphology of the Laplace carbide in HSS will not change during heat treatment, and thus it is necessary to pretreat the carbide into granular particles and improve the heterogeneity of carbide. Therefore, the forging quality of the cutting tools is very important.

(2) In order to improve the machinability of HSS, it is necessary to emphasis on the annealing and tempering process and the impact on the tool life [1, 2].

(3) HSS is high alloy steel that the treatment needs to preheating more than two times.

(4) There is a large number of carbides in HSS, which strongly prevent the growth of austenite grain when heated, even until the melting temperature, HSS still maintains fine austenite grains. Only when heated at a very high temperature and the carbide is dissolved enough, it can obtain high wear and red hardness, while toughness decreases with the increase of quenching temperature. The quenching temperature is very sensitive to the performance of HSS cutting tools, which is mainly depends on the quenching temperature. The best quenching temperature is selected according to the type of tool, the condition of use and the failure condition. The production of various cutting tools using steel with same grade and furnace number should have a larger difference between the quenching temperatures that the heat treatment process should be individualized [3]. Under the full utilization of toughness, the quenching temperature can be improved as far as possible to improve the wear resistance and hardness. (5) HSS has very high hardenability. According to the specific conditions, air cooling, oil cooling, and salt bath quenching can be implemented. (6) HSS cutting tools need to be tempered 3 times near the temperature of the two hardening peaks and4 times of tempering is needed for isothermal quenching.

Basic characteristics and classification of chemical composition of HSS is a tool steel with high carbon and high alloy. The content of carbon elements is generally from 0.7% to 1.6%, and the sum of the weight percentage of the major alloy elements, such as W, MO, Cr, V and CO, is between l0% and 40%. According to the different ratio of alloying elements, HSS can be divided into W-HSS, MO-HSS, W-MO HSS and high-performance HSS containing CO, AI and high V elements, respectively. Another characteristic that different from other types of steel is that the content of Cr element is fixed at about 4%.

3.3. Main Grade of HSS and Selection of Cutting Tools

Among the HSS cutting tools, the proportion of the tools made by the general HSS is the largest. At present, the output of the general HSS accounts for more than 80% of the total HSS. Wl8Cr4V (Wl8), which has a history of 100 years, is the earliest general HSS tool steel that the components were established and widely used in the world. Since the 40s of last century, after the composition establishment of general HSS W6MO5Cr4V2 (M2), the development and evolution of various kinds of HSS are based on the above two brands. Materials workers by testing W equivalent, replacing W with MO and adding CO, AI, V and other elements to increase the number of high speed steel to more than 100 kinds. Wl8 steel has low super-heat sensitivity, wide thermal plastic temperature range, strong anti-oxidation and decarburization ability, good machinability and grindability. The disadvantages of Wl8 steel is that the ledeburite organization is too coarse, distribution of carbides is uneven, thermal conductivity and thermal plasticity are poor, the toughness is low, and the productivity is not high. At present, the supply and demand of Wl8 steel are light, which is in the list of eliminated steel. M2 steel is the most international HS brand in the recent years, and its application is also the most widely used. The carbide particles of M2 steel are finer and well distributed. The strength and toughness of M2 steel are much better than those of Wl8 steel, but their overheating sensitivity is high, oxidative decarburization tendency is large and machinability is slightly worse. W9WO3Cr4V (W9) steel is a self-developed W-MO general HSS that metallurgical quality and process performance has the both advantages of Wl8 and M2, which has been incorporated into the national standard in l988, and has wide applied in China.

- The heat treatment of HSS cutting tools

The choice of quenching heating temperature depends on the content of main alloy elements in HSS such as C and W, MO, Cr, V, which determines the temperature range of quenching during final heat. The final quenching temperature is the most important parameter in the heat treatment process of cutting tool. The proper quenching and heating temperature can ensure that the tool has the necessary high hardness (including secondary hardening), high hardness and good toughness to meet the needs of lathe and machined parts. Generally, HSS with small balance carbon and high carbon saturation should be quenched at a lower heating temperature. Through the study of M2 steel, it is found that each 1% increase in carbon content, the temperature that grain boundary melting drops 11℃ [8]. On the other hand, if the carbon saturation is low, the temperature can chose the temperature above the middle limit to heat and quench that the carbide can be dissolved more fully, and obtain high thermal hardness and wear resistance. The morphology and distribution, dissolution and precipitation of abundant alloy carbides in HSS also affect the selection of quenching temperature. Under the conditions of more large grained carbide, serious carbide segregation, high level of macrostructure and large segregation of components, it should be quenched below the medium limit.

- Quenching temperature selection and quenching and tempering control of different cutting tools

The requirements of tool performance are different for different service conditions, different machining environment. In general, the cutting tools with simple shape, continuous cutting and single-edged semi-finished tools can choose higher quenching temperature. Other HSS cutters with complex shape, large thickness difference, super large size, slender structure can be quenched with medium and low temperature. In addition, for the products such as rod and tooth round saw blade, it is necessary to heat the surface locally in a high temperature salt bath furnace, and use the upper limit temperature to quench. While for the tools need whole heating in the high temperature salt bath furnace, the middle and upper limit quenching temperature can be selected for the small and medium size, and the lower limit quenching temperature should be selected for the larger size.

- Selection of heating time for quenching and heat treatment of large size cutting tools

The selection of quenching heating time is closely related to the temperature of quenching and heating. For HSS products, the selection of quenching heating temperature is the first choice. Within the range of temperature requirements for quenching process, the heating time can be relatively reduced

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for the higher heating temperature, while the heating time can be increased for the lower heating temperature. Usually, the quenching time can be calculated according to the effective thickness of the product, and the heating coefficient can be 8~10 S/mm. For cutting tools with small effective thickness, the heating time can take upper limit (the minimum heating time should not be less than 2 min), while if the effective thickness is large, it can take the lower limit. The choice of heating time for large size broach and hob can be determined according to the actual conditions of the field equipment and temperature. Generally, the temperature can be recovered to the set value at the high temperature heating furnace and heated for 8~10 min after heating. During the heating and cooling in the salt bath furnace, it must keep the single piece heating state. The heat treatment of large specification, except reasonable quenching temperature, holding time and choosing suitable fixture tools, another important key technology is how to take measures to ensure the hardness requirements of heat treatment and avoid cracking or severe heat treatment deformation. Through the accumulation of work experience in many years, the following measures are often taken to achieve better results in the process of actual heat treatment production. First, the poor design and improper processing of the potential heat treatment defects must be improved, such as reducing the sharp change of the cross section, increasing the corner of the keyway and avoiding the sharp angle of the gap to prevent the excessive local stress concentration in the tool heat treatment. Second, before final heat treatment, it can choose 2~4h high temperature tempering in the 720~760℃ range according to the actual situation of the workpiece to eliminate the processing stress and prepare for quenching organization [9]. Third, quenching heating and quenching cooling can use multistage temperature preheating, and multistage temperature isothermal technology. To prevent the cracking of tempering, the preheating can be increased when tempering [13]. Forth, to carry out low aging treatment after the heat treatment and finish of the products. With the extensive application of advanced machining equipment such as CNC machine tools and machining centers and the striving for high speed and high precision cutting, higher requirements for metal cutting tools are put forward, and HSS cutting tools are faced with great challenges. Therefore, the research and development of HSS tool material with high performance and heat treatment technology is the heavy responsibility of workers work on metal materials and heat treatment. Figure 4 shows some of HSS cutting tools.

Figure 4.
HSS cutting tools.

3.4. Problems in Heat Treatment Process of HSS Heat Treatment of HSS Cutters Has Made Substantial Progress Than Before.

Lots of tools have entered the international high-end market, and have been recognized by international instruments. But the gap is still very large that and shown in the following four aspects.

- Backward materials Powder

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HSS typified the level of HSS in twenty-first Century and has been widely used on complex cutting tools abroad, but it is still missing in China. At present, powder HSS used at home is imported materials. And the component of M42 and M35 HSS is not stable. Mixed furnace number and mixed steel grade cause lots of trouble.

- Poor machinery The domestic processing of HSS cutting tools still use the old type of salt bath furnace, whose environmental pollution is big, energy consumption is high, and the treatment of the three wastes is poor.
- Poor quality of personnel:

A considerable number of enterprises without qualifications of heat treatment engineer or technician. The tempers in most private enterprises without training and quality accidents happen frequently.

- Poor technology and equipment

The manufacturing technology of advanced heat treatment equipment is lagging behind the situation. Technology level and auxiliary material quality are not high and varieties are not enough. All of these factors restrict the development of heat treatment industry of cutting tools. The situation in which some tool plants always value cold processing and despise hot processing and this situation has not been fundamentally improved. It has been proved by practice that a unit that does not pay attention to heat treatment will pays the price and many of the gaps are caused by human beings. We are responsible for the task of reducing the gap between the advanced level of the world that talk less and do more practical things.

- Carbide Tools properties and specifications

The material of the cutting tool and its geometry play a substantial role on effectiveness, efficiency and overall economy of machining. Cutting tools fail occasionally due to mechanical breakage or rapid plastic deformation at their cutting edges and mostly due to gradual wear. Such failures by sudden breakage and rapid plastic deformation are extremely harmful and undesirable. An ideal cutting tool should possess several essential properties, some of which are often individually contradictory in nature and hence difficult to attain in a single-base material. Specific material coating technology substantially fulfilled such varying requirement from the tool. A thin but hard coating of more stable and heat-and wear-resistive materials like TiC, TiN, Al_2O_3, etc., of single or multiple layers, is selectively provided on the tough carbide inserts (substrate) by processes such as CVD, PVD, etc. in a controlled environment. The bulk core or substrate provides the desired mechanical strength, bulk toughness and high thermal conductivity for reducing tool temperature. The coating on the surface of the substrate provides added resistance to oxidation, corrosion, all types of tool wear, etc. as well as reduces friction at the chip-tool contact surfaces and thus enables enhanced tool life in machining both common and exotic materials. Even after rupture and progressive wear of the coating, it continues resisting tool wear without failure in actual performance with the help of its hard worn edges and fractured particles embedded in the substrate. In dry machining operations, tool is under go with high temperature leads to more friction and wear on the tool and the workpiece. This will result in increased tool wear and hence reduction in tool life. In dry machining, one has to counteract with alternatives for the beneficial effects of cutting fluids. One improved way of dealing with situation in dry machining is to use a coating of high thermal conductivity material over the tools [22]. AlTiN and AlCrN are coated on cemented carbide tool using arc-PVD process. These tools, along with the uncoated cemented carbide tool, are used to dry machine EN-8 grade steel in the experiment. Arc-PVD Deposition technique is used to coat the tools at 450– 500 °C for a thickness of 2–4 μm, for the two considered materials. A high current density in the arc spot causes explosive evaporation of metallic material. Dense plasma is formed as the material becomes highly ionized. The high ionization results in good adhesion and dense coatings. The metal ions and the reactive gas atoms form the hard coating on the cutting tool, which is placed in a vacuum chamber. The base material for all the cutting tools is cemented carbide. As for the workpiece, EN-8 grade steel is used.

1-Thermal Insulation – Heat at the cutting edge is a primary reason why tools break down. Coatings bond a thermally insulating barrier to the tool to reject heat from the tool surface back into the chip, thus protecting the tool substrate and making it last longer. Some coatings, such as TiAlN and AlTiN under certain conditions, actually produce a hard layer of aluminum oxide (an excellent insulator) during the cut.

2. Mechanical Strength – Abrasion from the chip combined with microscopic roughness of the tool surface tends to wear the substrate and dull the cutting edge during normal operations. The high hardness, lower friction coefficient, and reduced surface roughness of coatings allow the chip to the surface of the tool. This reduces built up edge and wear so tool life is increased.

3. Chemical Resistance – Heat, pressure, coolant, and workpiece material all add to the chemically reactive forces present at the cutting edge. When reactive elements are brought together under these conditions, the uncoated tool will degrade. Coatings protect the tool substrate from exposure to these reactive forces thus stabilizing the cutting edge even under the harshest conditions.

4. Results and Discussion

4.1. Tools Before and After Operation

Table 1 shows the conditions and figures of operating studied tools.

Table 1.
Working conditions of studied tools.

Cutting speed	**1500 RPM**
Operating time	15 hours
Feed rate	0.1 mm/min
Cooling /Without cooling	With cooling

Figure 5 shows the tools photo before operation and after operation of Carbide 12 mm.

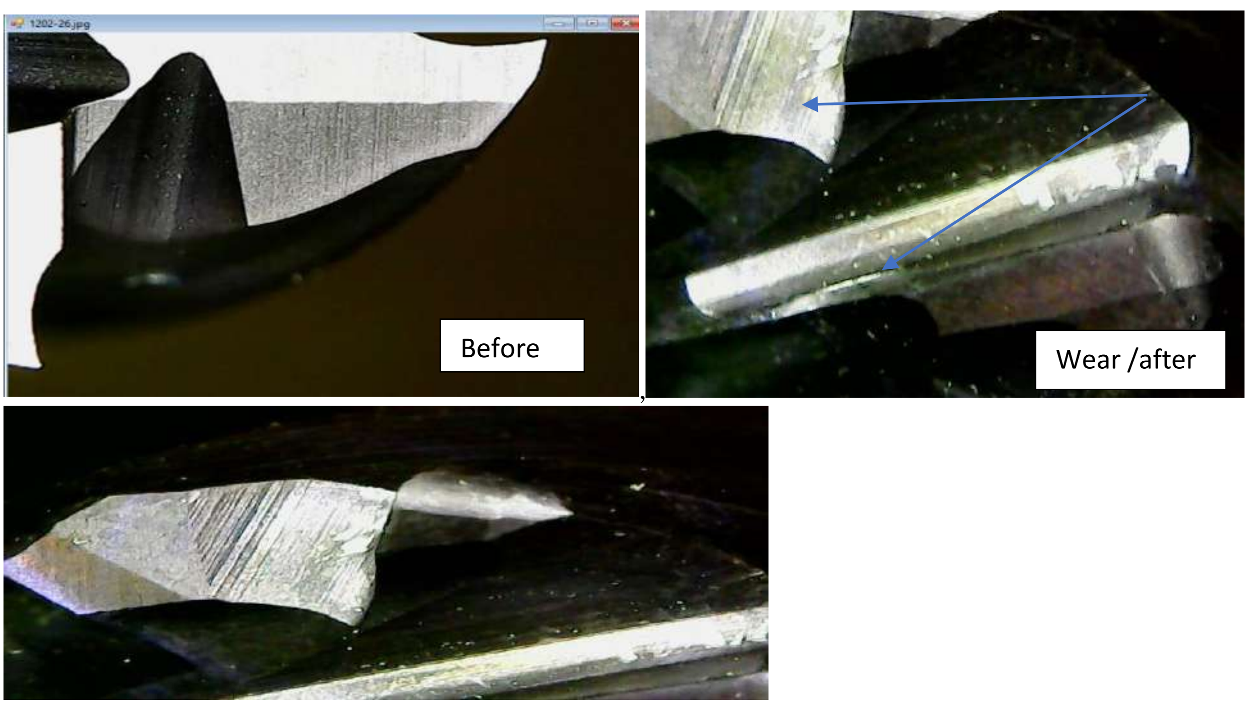

Figure 5.
Wear of carbide tool -10 mm.

Figure 6, 7 and 8 show the wear on different other tools.

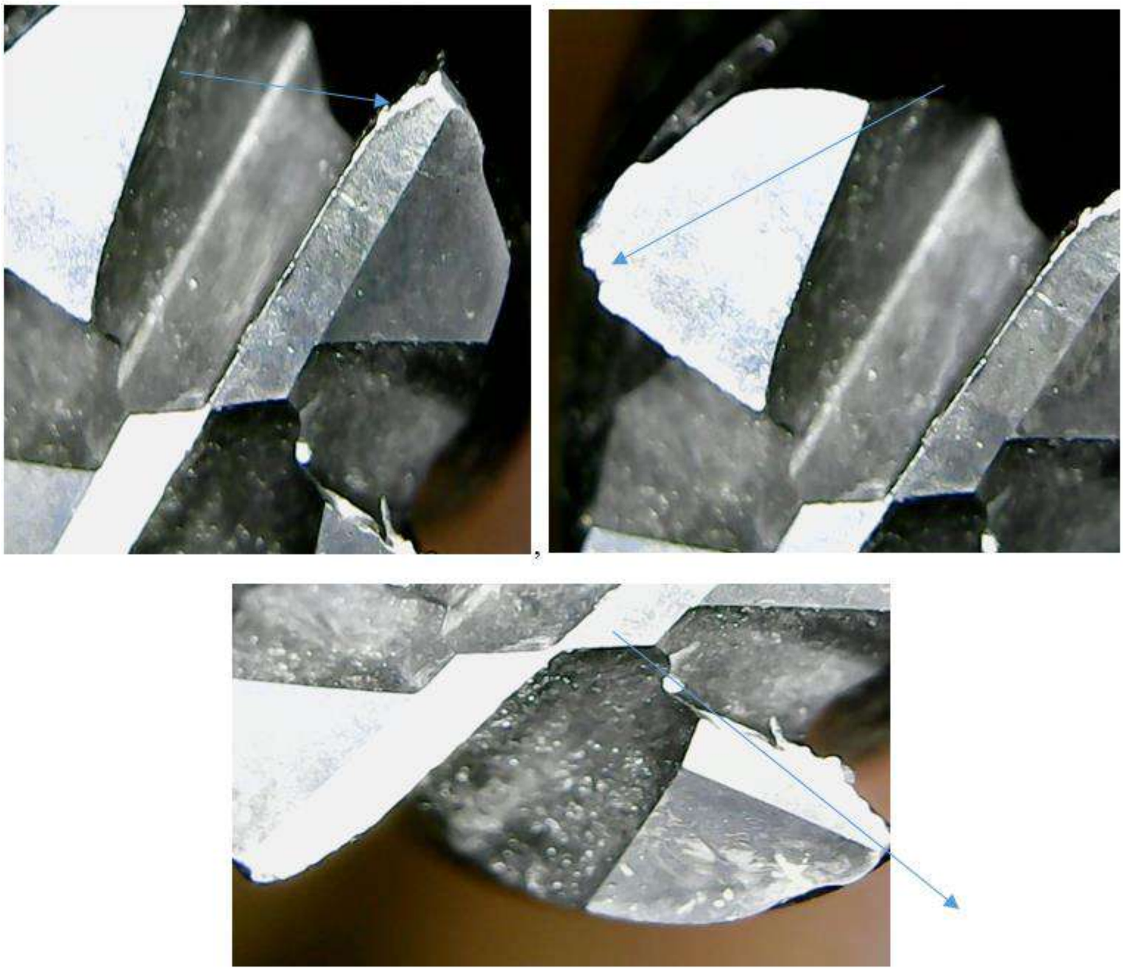

Figure 6.
Wear in carbide tools.

Figure 7 shows wear in HSS 10 mm tool.

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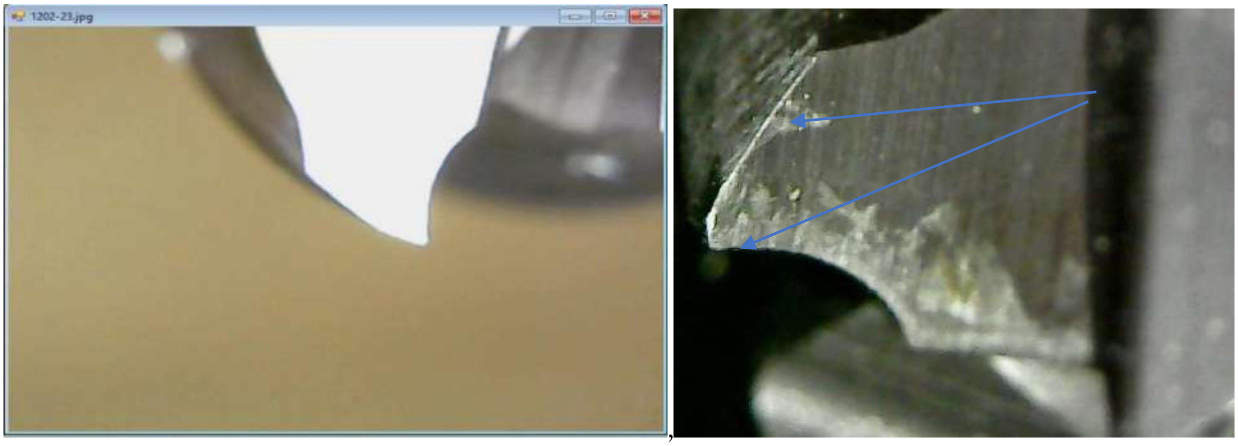

Figure 7.
Cutting tool HSS -10 mm before and after operating.

Figure 8 shows the wear in the HSS -12 mm cutting tool

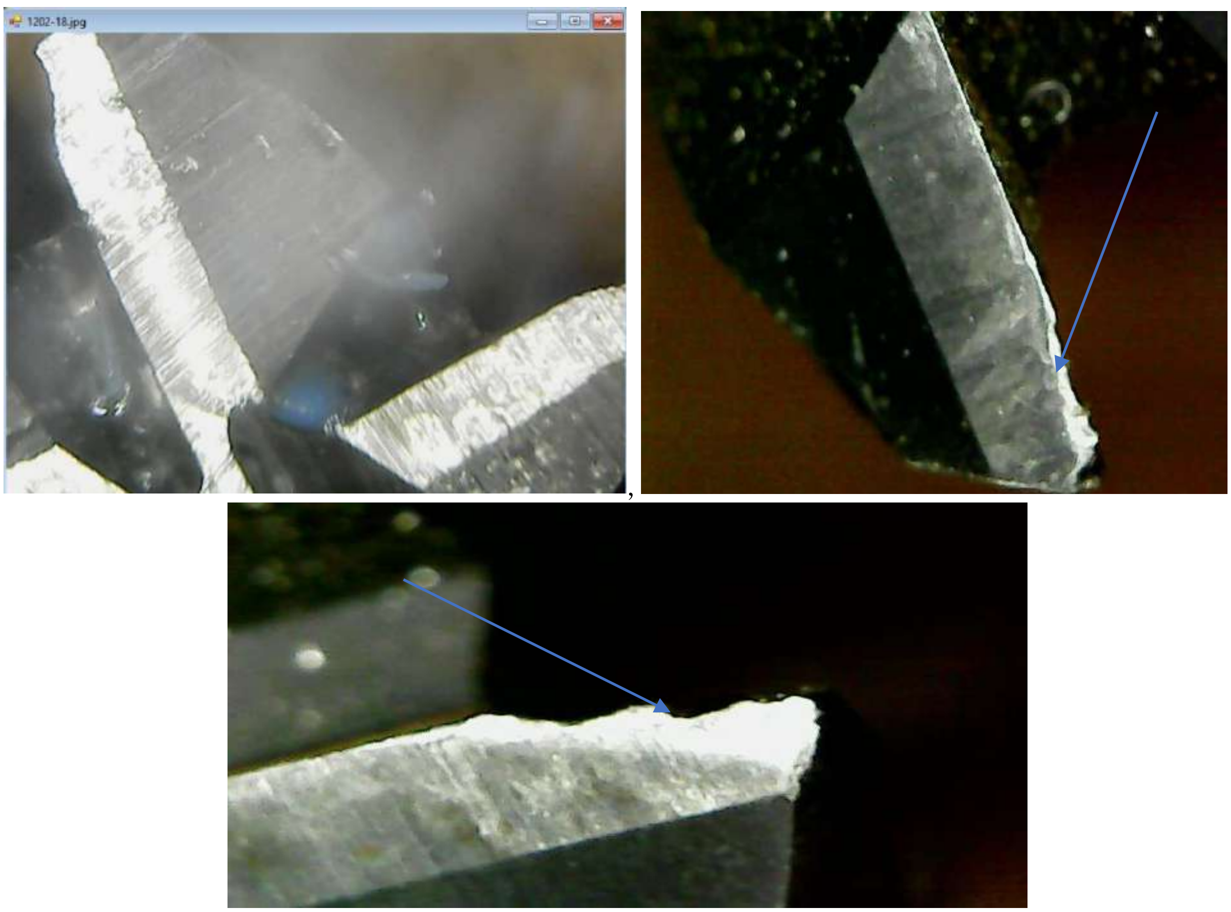

Figure 8.
Wear in HSS-12 mm cutting tool.

4.2. Roughness Values

The roughness values before and after operating the tools samples will be compared

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- Carbide 10 mm tool

4.2.1. Before Operating the Tool

Figure 9 represents the Carbide tool -10 mm roughness diagram and profile before operating the tool.

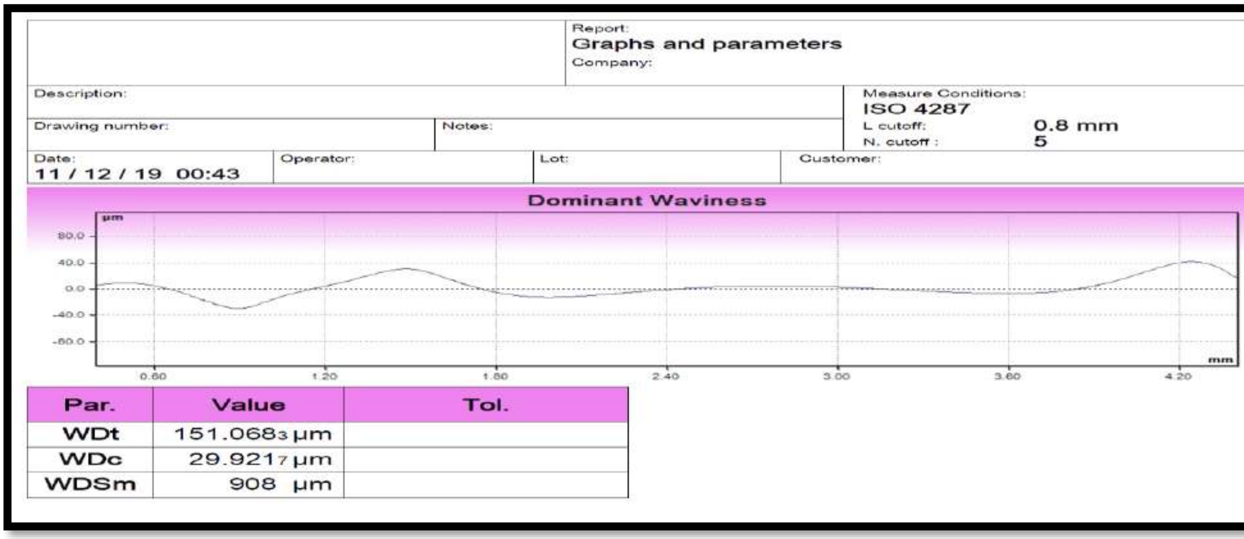

Figure 9.
Carbide 10 mm tool roughness profile.

- Carbide Tool 10 mm after operating the tool

Figure 10 shows the roughness profile and values after operating the tool.

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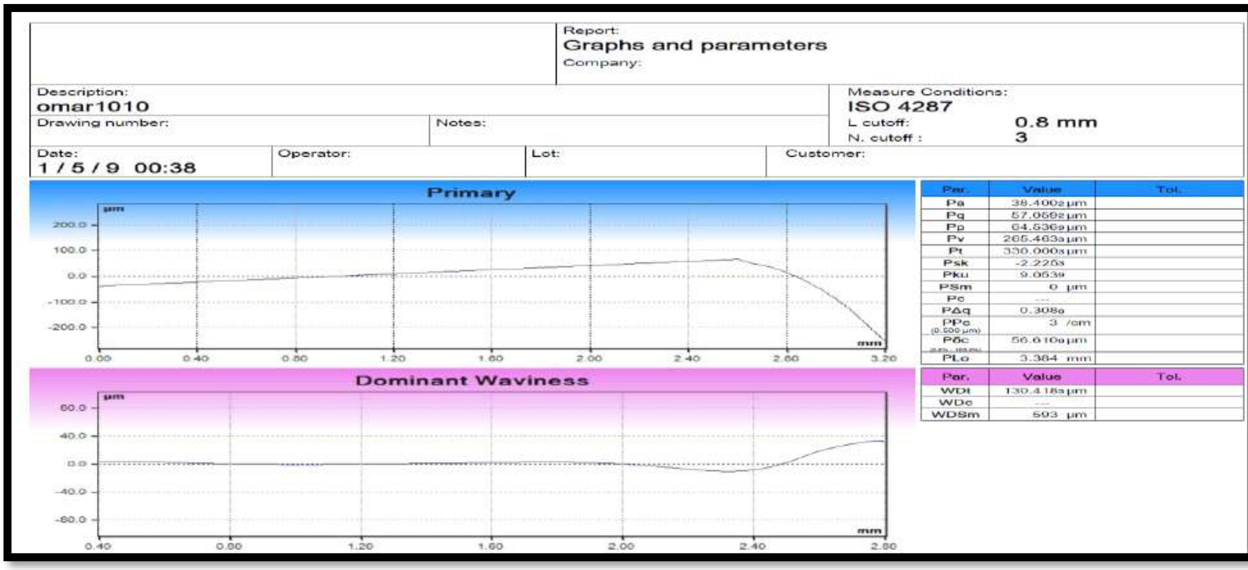
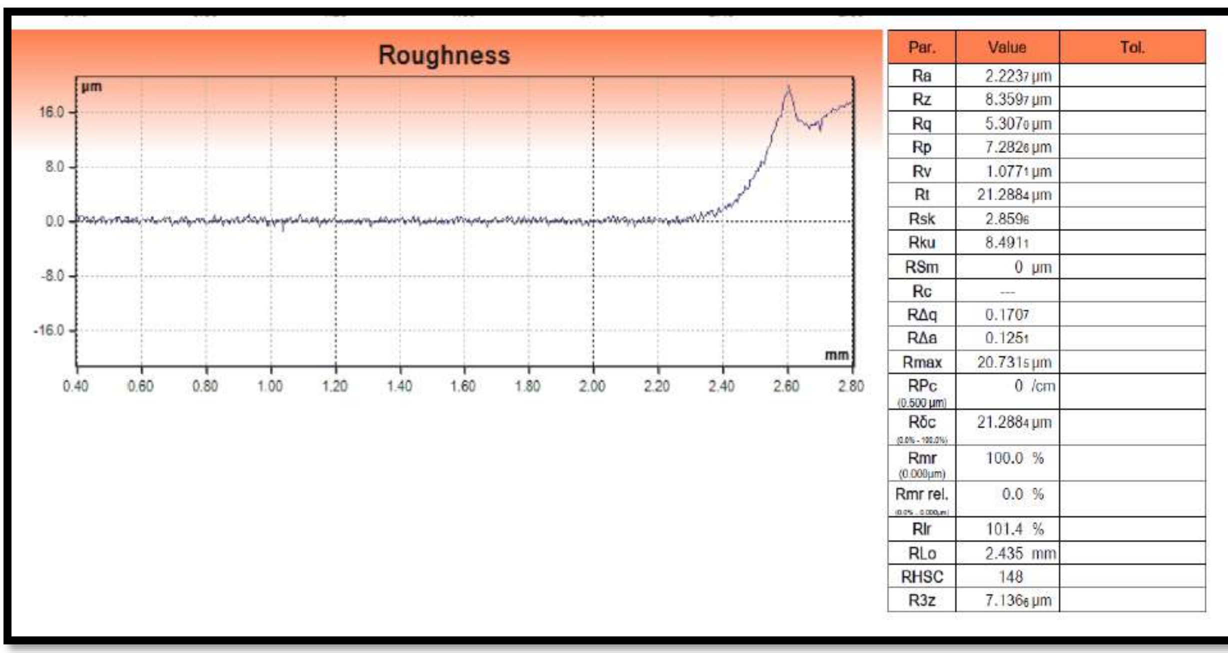


(a)



(b)

Figure 10.
(a) and (b) Roughness values and profiles of Carbide tool -10 mm.

It can be noticed that (because of the wear in cutting edges of the tool) the roughness values after operating the tool are lower than that before operating the tool. The roughness profile (Fig.5.7 b) is steady and laminar (=0 value) till the cutting edge (reaches about 18 micrometer).

- Carbide Tools -6 mm

Figure 11 (a, b, c, d) represents the Carbide tool -6 mm roughness diagram and profile before operating the tool.

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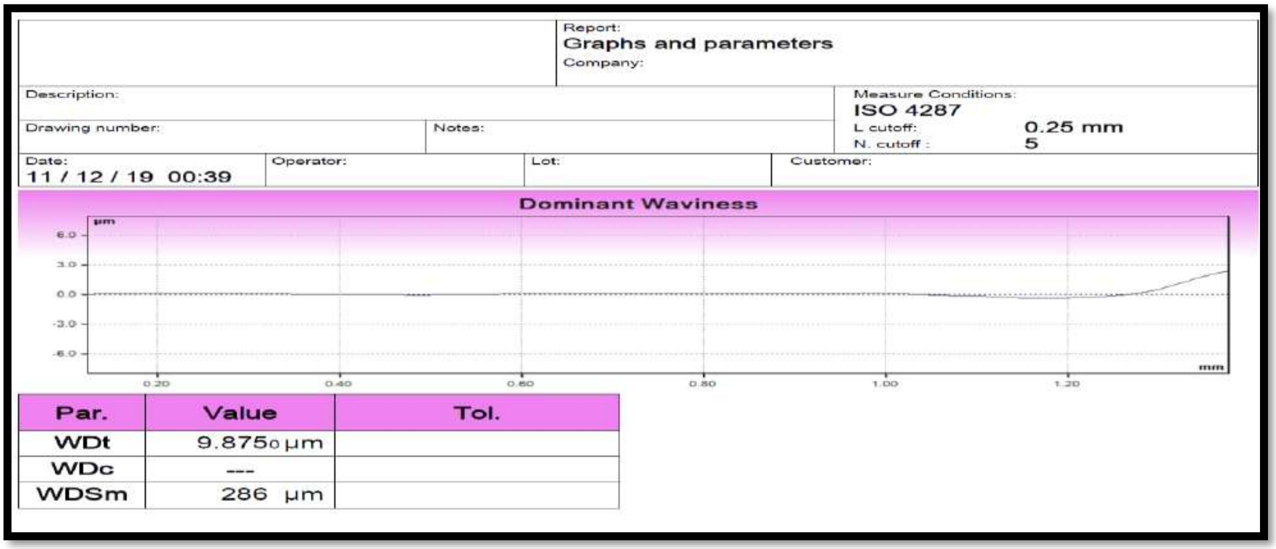
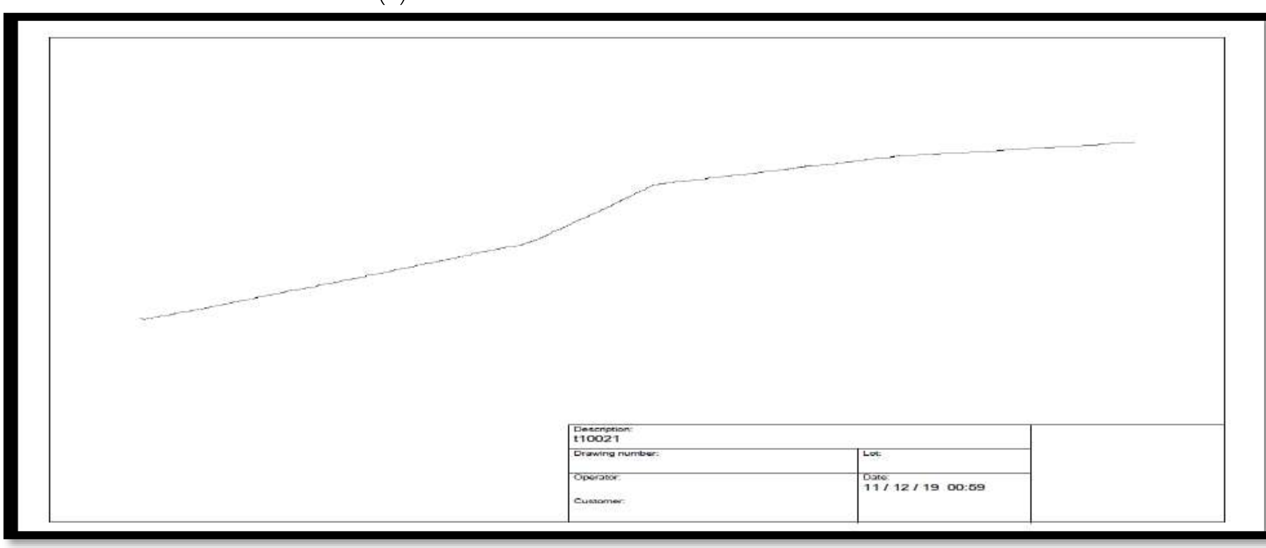
-Before


Report:
Graphs and parameters
Company:
Description:
Drawing number:
Notes:
Measure Conditions:
ISO 4287
L cutoff: 0.25 mm
N. cutoff : 5
Date:
11 / 12 / 19 00:39
Operator:
Lot:
Customer:
Dominant Waviness
µm
6.0
3.0
0.0
-3.0
-6.0
0.20
0.40
0.60
0.80
1.00
1.20
mm
Par.
Value
Tol.
WDt
9.8750 µm
WDc

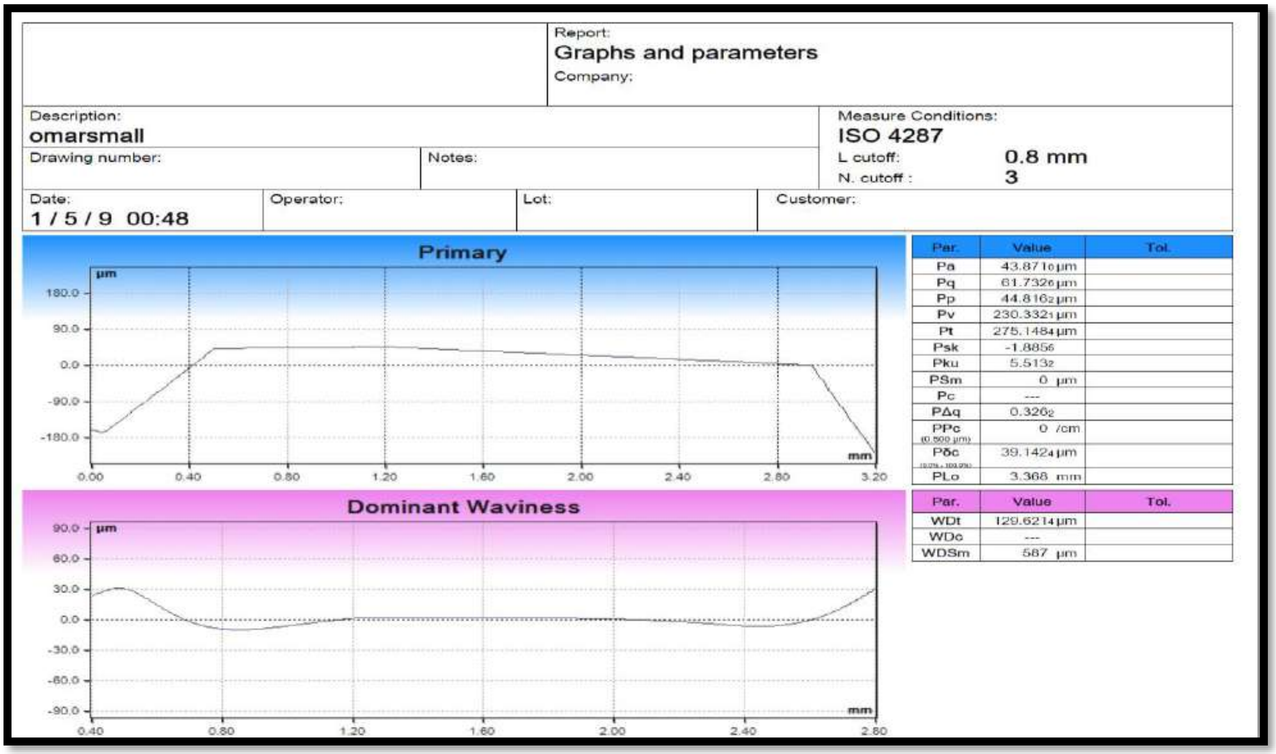
WDSm
286 µm

(a)


Description:
t10021
Drawing number:
Lot:
Operator:
Date:
11 / 12 / 19 00:59
Customer:

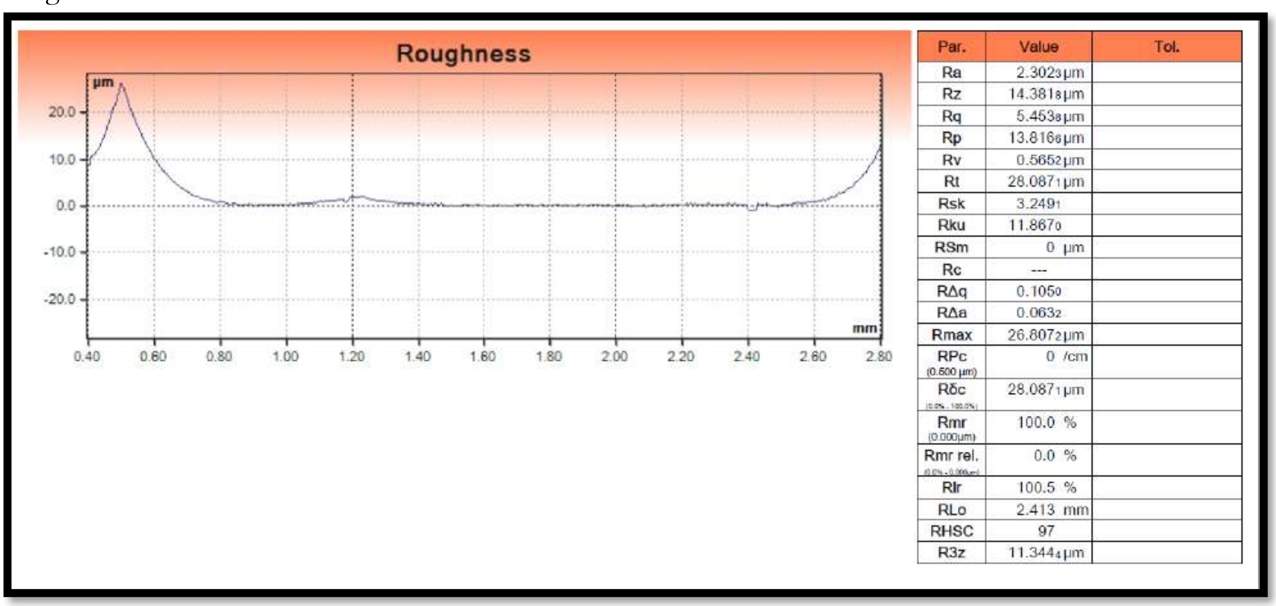
(b)

-After



(c)

Roughness



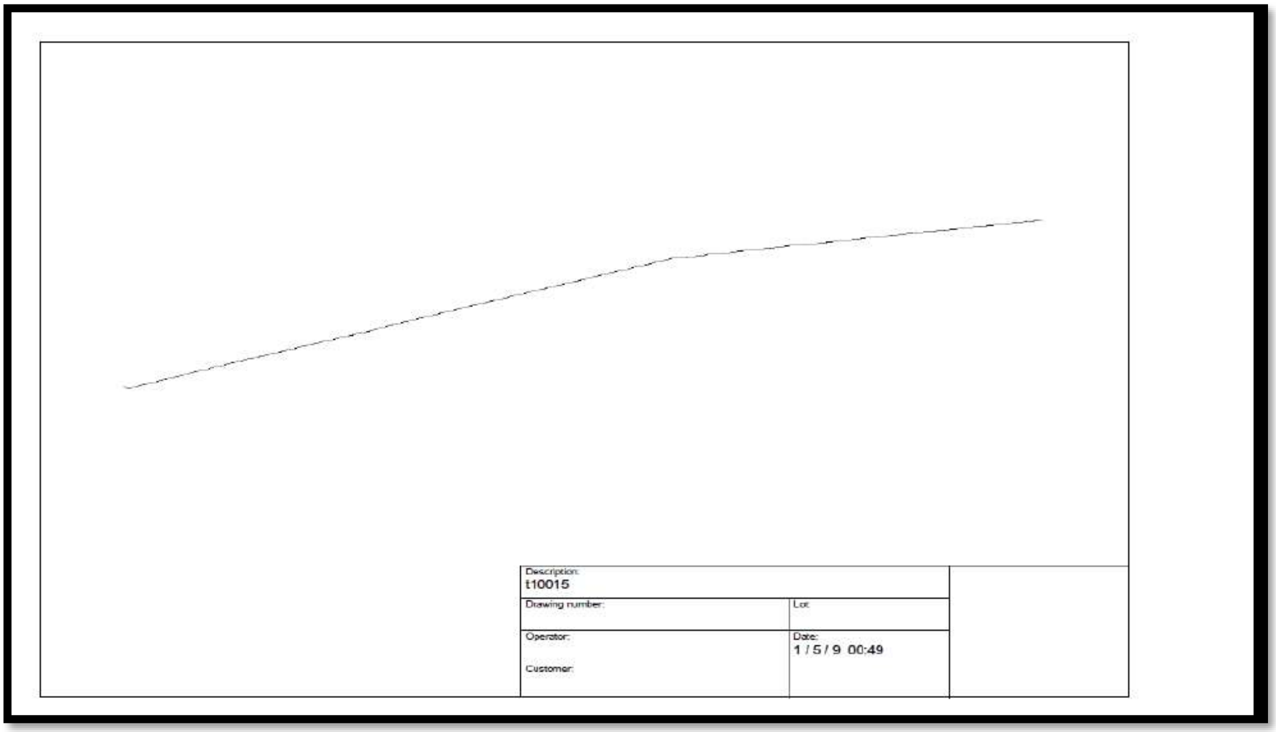
(d)

Figure 11.
(a, b, c, d). Wear in the cutting tool of Carbide-6 mm.

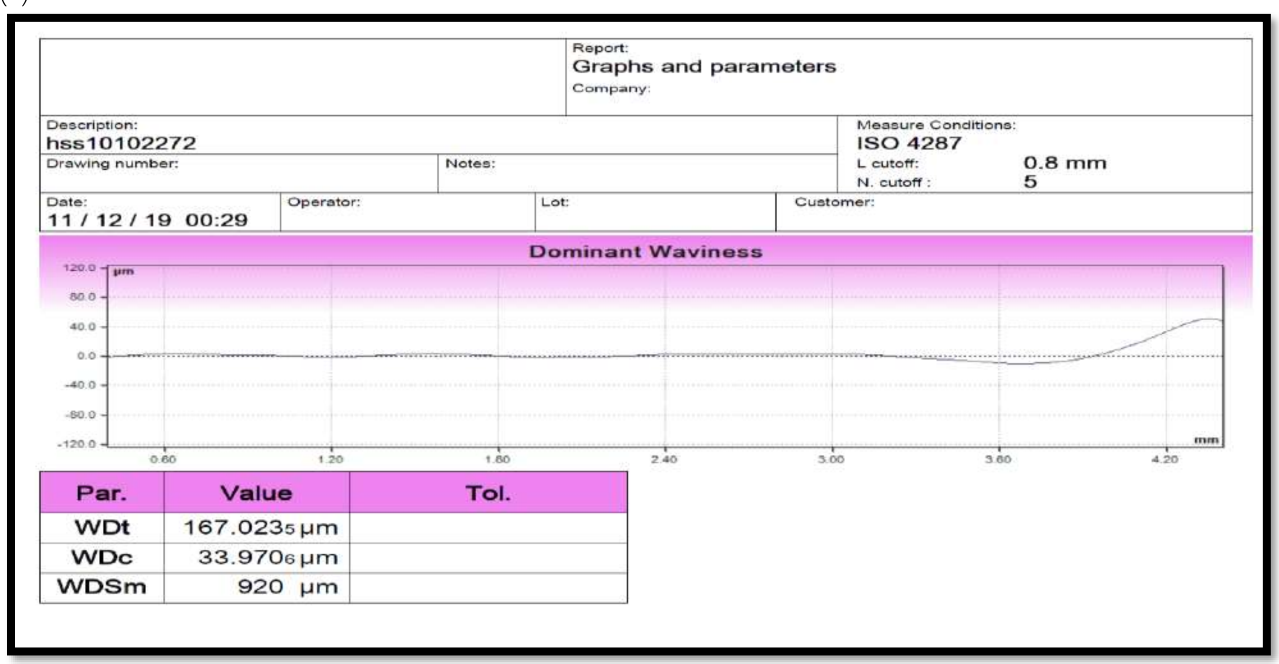
- HSS 10 mm Tools

Figure 12 (a, b, c, d) represents the HSS tool -10 mm roughness diagram and profile before operating the tool.

-Before



(a)



Par.	Value	Tol.
WDt	167.0235 µm	
WDc	33.9706 µm	
WDSm	920 µm	

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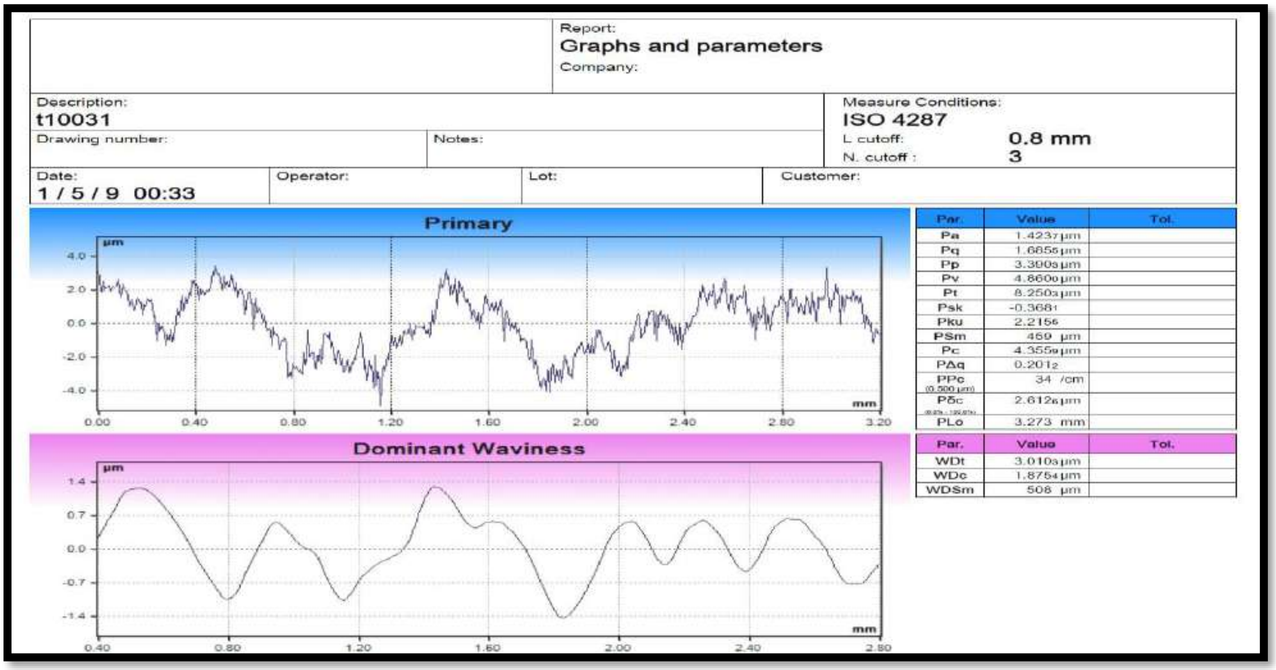
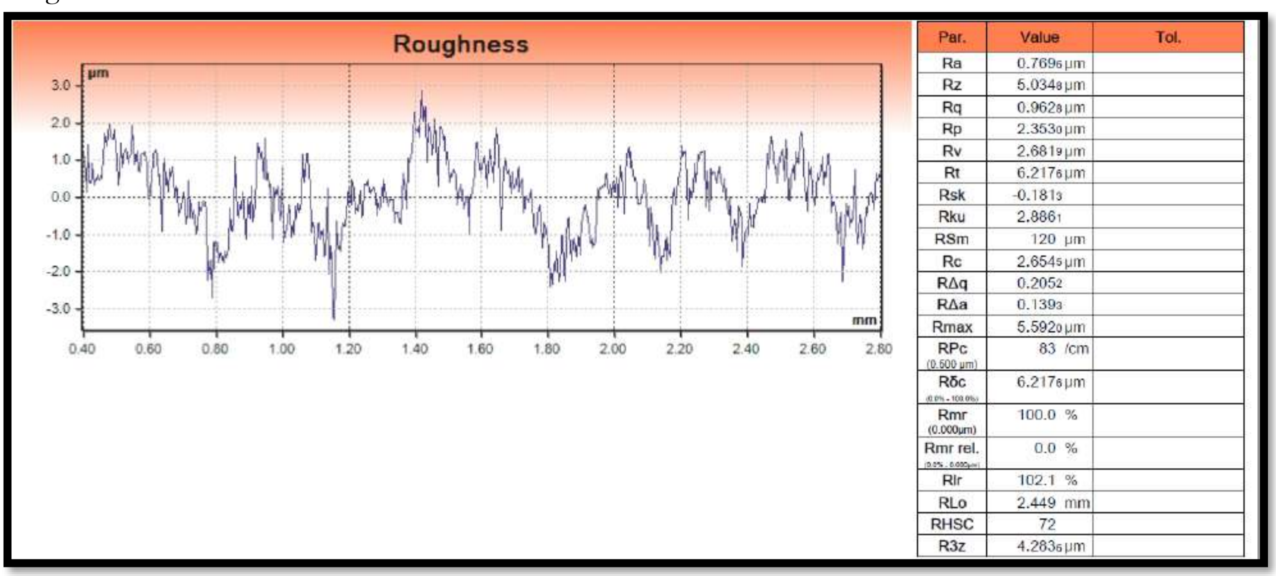
(b)

-After operating the tool



(c)

Roughness

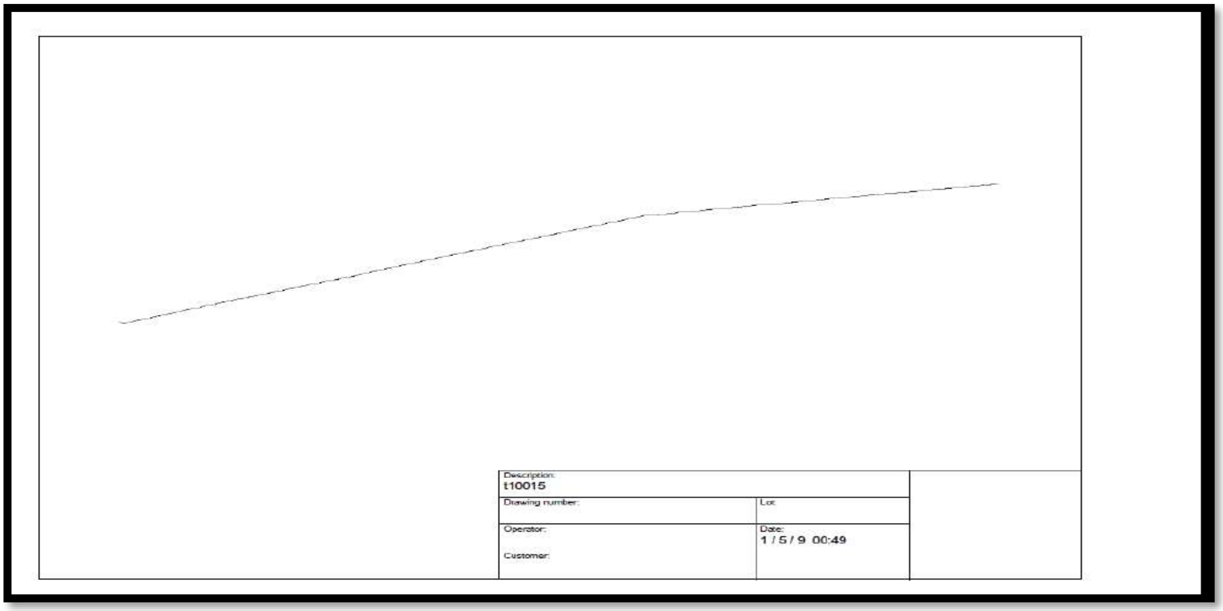


(d)

Figure 12.
(a, b, c, d). HSS tool -10 mm roughness diagram and profile before and after operating the tool.

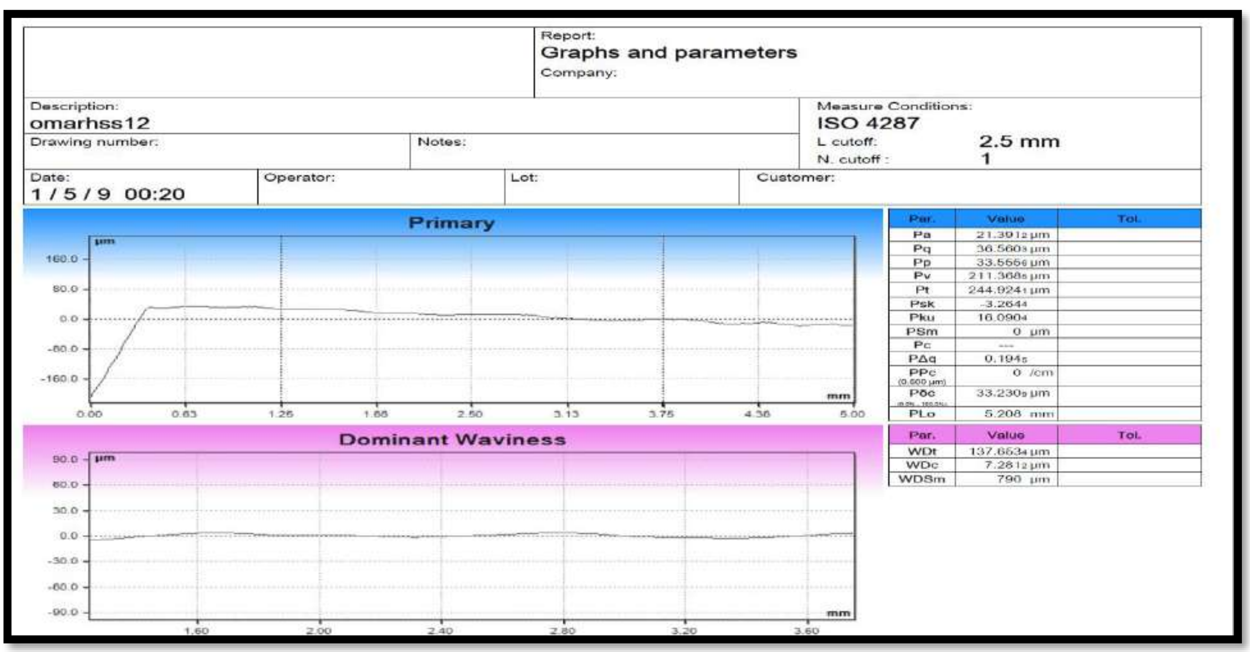
- HSS 12 mm Tools

Figure 13 (a, b, c, d) represents the Carbide tool -12 mm roughness diagram and profile before and after operating the tool.
-before



(a)

-after operating the tool



(b)

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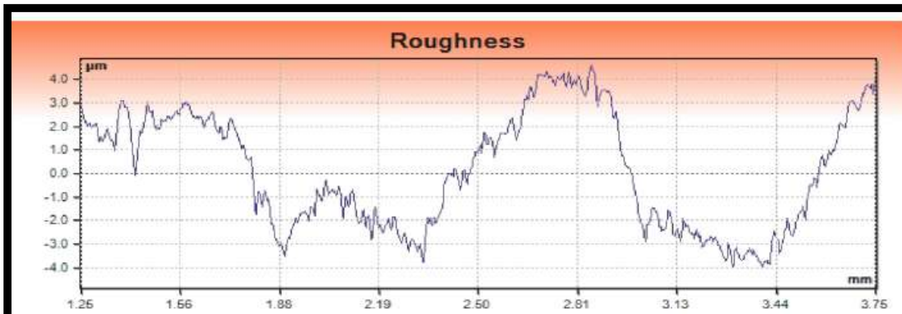
Roughness



Par.	Value	Tol.
Ra	2.2060 µm	
Rz	8.7867 µm	
Rq	2.4493 µm	
Rp	4.6157 µm	
Rv	4.1710 µm	
Rt	8.7867 µm	
Rsk	0.1496	
Rku	1.6346	
RSm	0 µm	
Rc	---	
RΔq	0.0771	
RΔa	0.0565	
Rmax	8.7867 µm	
RPc (0.500 µm)	0 /cm	
Rδc (0.0% - 100.0%)	8.7867 µm	
Rmr (0.000µm)	100.0 %	
Rmr rel. (0.0% - 0.000µm)	0.0 %	
Rlr	100.3 %	
RLo	2.506 mm	
RHSC	6	
R3z	8.2456 µm	

(c)

Figure 13.
(a, b, c). The HSS tool -12 mm roughness diagram and profile before and after operating the tool.

5.3. Discussion

According to the most recent data and tables, these tools experience some wear after operating for 15 hours. This wear may be visibly measured by comparing the cutting edges of the tools; also, the roughness tests revealed varying results, indicating that some wear values are recorded. After working for 15 hours, it is evident that the roughness values of these tools differ from those obtained before working in the majority of the samples examined. In carbide tools, these values decreased by 5%, but in HSS tools, they reach 25%, indicating that HSS tools have more wear than carbide tools. Also results showed that the roughness profiles for all tools become more wavey and fluctuate but with low overshooting to cutting edges because of wear.

5. Conclusions

This study aims to investigate and examine experimentally wear values and profiles occurred in both HSS and carbide tools after some time of working on milling machines. Based on this investigation, the following findings can be drawn

-All tools face wear after some number of working hours, but this is vary and depends on many parameters like:

- Type of tool material
  Type of workpiece (its hardness, brittle or ductile, its strength…..).
- Working conditions and variables: cutting speed, feed rate, cooling / without cooling …etc.
- It is found that wear values in HSS tools (for 15 working hours and for the same working conditions) are more than that of carbide tools
- Investigating wear using visual methods can be noticed by comparing the cutting edges using eyes or digital microscope can give an indication about wear existence but cannot quantify them.
- The roughness values are used to give some indications about wear and its values, and it can be noticed that as the tools' working hours increase the cutting edges vanished and so the roughness decreased.
- The roughness profile for some studied tools may be become more wavey but with lower values of roughness.

Transparency:
The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Copyright:

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Appendix A.
Digital microscope.

Appendix B.
Tools after operating.

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