International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 1, January-2019

DIAMOND TOOL WEAR MEASUREMENT METHODS: A REVIEW

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Abstract: this paper presents a state of art review on single point diamond tool wear measurement methods. Ultra-precision machining refers to the machining where machining is done at atomic scale. This makes the process different from conventional machining process. High quality surfaces are generated by ultra- precision machining. Diamond turning is most widely used due to the unique properties of diamond such as good heat conductivity, high hardness and high wear resistance. Due to these properties diamond is used as a most suitable tool material in ultra precision machining. It generates mirror like finishing. Diamond tool wear is one of the major issues with diamond turning that increases the process cost significantly. Various methods are used for measuring, monitoring and reducing diamond tool wear. In this paper many methods of measuring diamond tool wear, monitoring tool wear behavior and reducing tool wear are given.

Keywords— Ultra- precision machining; Single point diamond turning (SPDT); wear; wear measurement; wear monitoring; wear controlling

I. INTRODUCTION

Diamond is one of the two allotropes of carbon. Its tetrahedral structure makes it different from graphite. Because of the covalent bond of each carbon atom with other four carbon atoms, high energy is needed to separate this bond [1]. Diamond is used as a gem but its properties of high heat conductivity and hardness [1-3] makes it different from other gems and most suitable material for cutting tool. Due to its brittle nature all the materials are not easily turnable from diamond tool. Some easy to cut or diamond turnables materials are aluminum alloys, copper, brass, tin, PMMA, polycarbonate, gold, silver etc [4]. Diamond non- turnables are nickel, ferrous metals, silicon carbide and the metals that have unpaired d electrons [5]. Diamond turning is most widely used in optical industries due to its nano level finishing and micron level form accuracy. SPDT is used for the fabrication of different materials like metals, polymers and crystals. It has applications in the field of precision drums, mirrors, IR optics, medical devices, lenses etc. Processing of some emerging materials in the field of optics such as silicon, germanium, steels and polymers are difficult to be machined by diamond tool. Silicon is difficult to be machined by diamond due to its brittle nature while steel is difficult due to its ferrous nature. Diamond tool wear is one of the most important factors that affect the surface finish of the processed material. After machining up to particular distance, diamond tool fails to give good quality surface due to its wear. SPDT tool is shown in fig. 1.

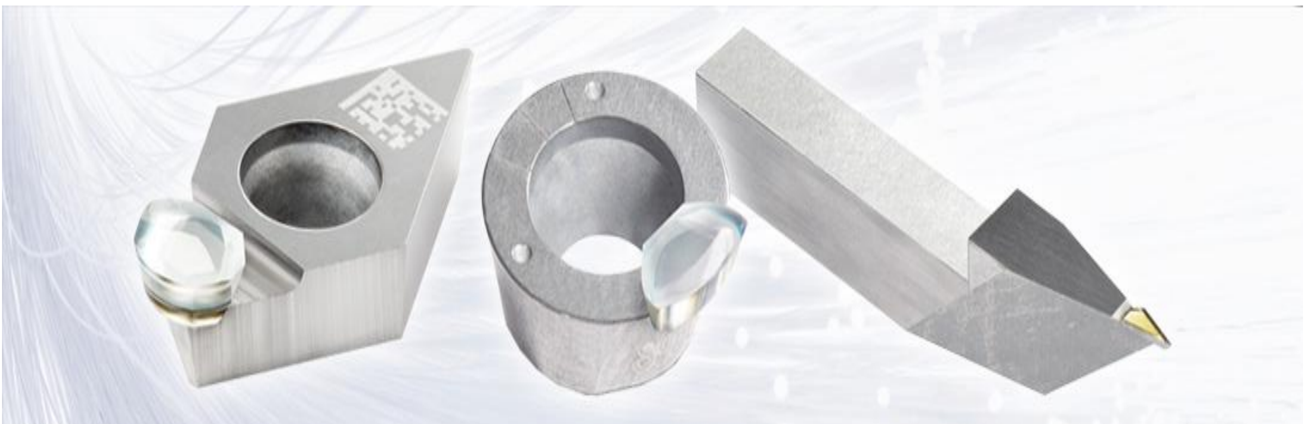

Fig. 1: Single point diamond turning tool

Machining distance or tool life varies for material to material. Single point diamond turning is the most effective method to achieve nano-metric surface finish and it is used to cut hard materials also that made researchers to focus their studies on behavior of diamond tool wear, their causes and tool wear measurement. A general set up of SPDT is shown in fig. 2.

Fig. 2: Single point diamond turning set up

A number of methods are being used to measure diamond tool wear still the problem is alive due to its nano-metric edge radius. Studies have been conducted to reveal the behavior of diamond tool during machining under different circumstances and for different materials. Many attempts have been done to measure the diamond tool wear quantitatively and qualitatively, SEM with dual detector, EBID method of SEM [6-8], AFM and changes in parameters method are used to measure the tool wear of diamond. Some researchers are going on to study the optimum conditions to minimize diamond tool wear. Some researchers are going to find out an effective method to measure nano level edge radius of diamond tool. As compared to the conventional machining diamond turning cuts at much smaller depth. Various types of diamond tool wear occur during machining that are mechanical wear, chemical wear and physical wear.

a) **Mechanical wear** can be seen due to the rubbing of hard particles of the work piece. Thus the friction between tool edge and work piece interface takes place. This happens because the temperature between the work piece and tool chip interface increases.

b) **Chemical wear** happens because of the chemical reactions between work piece and carbon atoms of diamond tool. Ed Paul et al. [5] investigated chemical aspects of tool wear in single point diamond turning. They presented that Chemical wear occurred due to unpaired electrons in work piece that are to be turned by diamond turning and also provided a table representing non turnable materials and number of unpaired d electrons for each individual. E. Brinksmiser et al. [9] presented a study on ultra-precision diamond cutting of steel molds. In this study they revealed that diamond tool wear while cutting steel was mainly due to chemical wear mechanism. In case of diamond turning of steel, diamond tool wear occurred because of graphitization, diffusion, carbonization and oxidation this happened because of the presence of unpaired 'd ' electrons in the work piece. In this study they used white light interferometer for measuring the surface roughness at different machining distances. They proved that diamond turning was possible for steel alloys if surface zone of work piece was modified thermo chemically. So that the chemical reactions between carbon atoms of diamond lattice and work piece material could not take place.

c) **Physical wear** is because of the anisotropy of diamond. Static discharging between tool and work piece results thermo electric wear. GPH Gubbels et al. [10] studied diamond tool wear when cutting amorphous polymers. In this study, glassy polymers were used by them as a work piece material. Here SEM was used to take the images of diamond tool. This study showed the results obtained during the cutting of polycarbonate in dry environment as well as in humid environment and dry cutting of polycarbonate resulted discharging. Dry cutting of polycarbonate worn diamond tool more in comparison to polycarbonate cutting in humid environment. O. A. Olufayo et al. [11] stated that during the machining of polymer adhesion of tool chip shows the presence of electrostatic force field. They identified two wears during polymer machining that were tribo chemical wear and tribo electric wear. They used response surface method for the selection of parameter combination. They reported that tool wear mainly occurred due to static charging.

Fig. 3 shows the worn out edge of diamond tool where wear land can be easily seen.

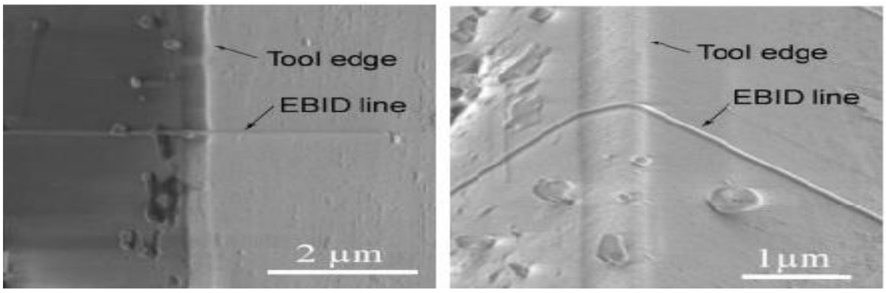

Fig. 3: SEM images of Diamond tool wear [6]

Diamond tool wear measurement

Diamond tool wear measurement is a difficult task because of the nano metric range of diamond tool edge radius. Methods that are used for measuring it are direct and indirect methods. For diamond tool wear measurement proper understanding of tool wear behavior is necessary. Diamond tool wear measurement methods are given in fig. 4.

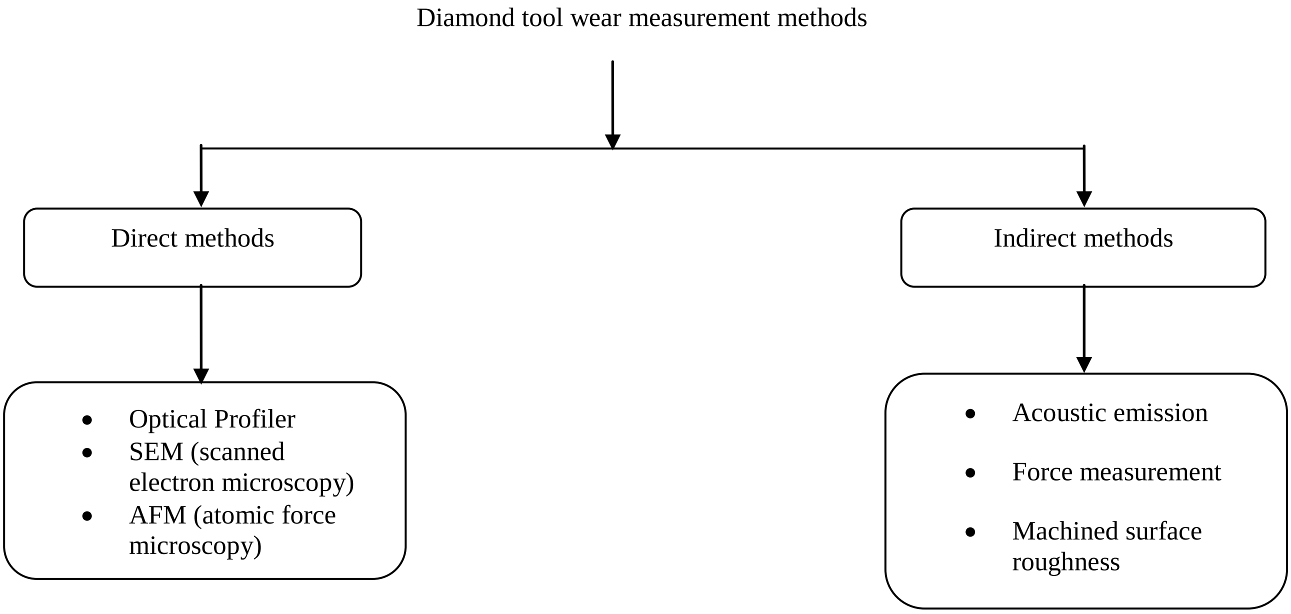

Fig. 4: Methods of measuring diamond tool wear

Indentation method also known as plunge cut method can also be used to measure diamond tool edge radius. By which tool wear can be calculated quantitatively [12]. M. Sharifuddin et al. [13] investigated the performance of single crystal diamond tool in ductile mode cutting of silicon. This study represented the tool wear behavior for different diamond crystal orientations. In this wear patterns were studied in terms of cutting distances. This experiment was done with the help of indentation test before and after machining. Then indentation was measured in AFM. This gave the value of edge radius or showed the sharpness of tool. Machining was performed on silicon wafer and after specified intervals tool wear land was measured in Nomarsky optical microscope. SEM gave the close view of wear land and chips were examined by EDx analysis. This experiment showed that in this case predominant wear was gradual wear and as the distance increased some small grooves were also observed. Crater wear was also there on rake face. Study gave longer tool life for {100} rake {110} flank orientation of diamond tool. Li Dan and J Mathew [14] reviewed tool wear and failure monitoring techniques for turning. This study showed direct and indirect methods of tool wear monitoring. Optical measurement method was used as a direct method of tool wear monitoring which includes SEM and AFM etc. Indirect method included changes in parameters like change in force, vibration, temperature, power input, roughness of machine surface and Acoustic emission method (pattern recognition concept). Changes in above parameters during machining were also an indication of tool wear during machining.

Diamond tool wear monitoring

It is also important as it gives an indication of tool wear. It can also be said that tool wear monitoring is indirect measurement method of diamond tool wear measurement. Diamond tool wear is monitored by observing sudden change in parameters during machining. Diamond tool wear can be observed if there is any sudden change in acoustic emission [15-16], force [12][17], noise, surface roughness and signal processing[18]. In Hyu Choi and Jeong- Du Kim [18] stated a monitoring system on diamond tool wear. Aluminum plate was used as a work piece material. This study proposed a new method of monitoring diamond tool by using frequency response of multi sensor signal. This represented the tool wear in terms specific frequency band. Wear signals showed different energy bands and average energy was monitored continuously. Four stages of tool wear were shown. First initial wear took place then normal wear occurred after this wholly wear of tool took place and at the end tool breakage occurred. Dynamometer was used to measure forces; accelerometer was used to measure vibrations in the study. At the end it was explained that during the time of tool wear control actions must be taken in terms of regrinding the tool.

Diamond tool wear controlling

Diamond tool wear can be controlled by proper selection of tool, suitable environment, coolant, vibration and most suitable parameters. Selection of tool proper geometry affects tool wear thus effective rake angle, nose radius etc must be selected [3]. Vibration is one of the uncontrollable parameters that cannot be eliminated it can only be controlled [19]. Vinod mishra et al. [19]presented their work on experimental investigation on uncontrollable parameters for single point diamond turning. Aluminum was used as a material for experiments by them and surface finish was analyzed by CCI (coherence correlation interferometer). Study of uncontrollable parameters for example vibration, tool wear and change in material condition had done. They showed that Tool overhead (TOH) was the main factor that contributed for tool work piece vibration. Dynamic balancing of machine directly affected surface finish of work piece. Selection of suitable environment also affects tool wear. By providing cryogenic cooling in tool work piece interface, chemical wear can be reduced [5].

II. CONCLUSIONS

The Diamond turning is the most effective method by which mirror quality surface finish can be achieved. This type of surface finish and micron level form accuracy made this area of interest for researchers. Studies have been conducted to reveal the behavior of wear of diamond tool, optimum parameters for machining for different materials. Many studies have been performed to measure diamond tool wear qualitatively and quantitatively. Still diamond tool edge radius is difficult to measure because of its nano meter range. A list of points drawn from the above review is given below:

- Cutting tool left its impression on the machined surface of work piece. Thus worn out tool makes the surface finish inferior.
- SEM is a high resolution device. It can give 2D information of tool profile but 3D informations are not available.
- In SEM, It is most difficult task to focus and align nano metric edge radius of diamond tool.
- Direct and indirect methods are available for diamond tool wear still accurate results are not obtained.
- It is very difficult to focus the work piece in optical profilers thus there was a requirement of special purpose holding devices.

III. FUTURE TRENDS

Diamond turning is an expensive process. A small extent of diamond tool wear can directly affects the surface finish and thus increases the process cost. This is an emerging field for industries. There is a very wide scope of diamond turning in future. Optimization of process parameters for newly developed materials can be done. New techniques for measuring diamond tool edge radius can be used by which accurate value of tool wear can be found. Special purpose holding devices can be designed so that accurate focusing in optical profiler can be done for accurate measurements. Some other parameters of surface roughness of machined work piece like skewness, kurtosis etc. that directly or indirectly affects the diamond tool wear can also be monitored that shows an indication of tool wear during machining. Diamond tool wear behavior and tool life studies can also be conducted to understand tool life.

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