A Comprehensive Report on Computational Analysis of Single Point Cutting Tool

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Abstract— The cutting tool plays a very important role in the machining process of a part in production. It not only performs the cutting action but helps in getting required surface finish and accuracy of the part. In order to perform these tasks the tool has to be strong enough to withstand wear resistance and serve for long period of time to produce more number of components with the same accuracy. Machining is important in metal manufacturing process to achieve near-net shape, good dimensional accuracy and for aesthetic requirements. In this paper a comprehensive report has been presented in the area of single point cutting tool research and development for various applications.
Key words: Crane Hook, FEA, Stress

I. Introduction

(Today's modern industries, the basic mechanism of forming a chip remain the same even with the development of all the sophisticated equipment and techniques. The history of cutting tools began during the industrial revolution in1800 A D., the ever-increasing importance of machining operation is gaining new dimension in the present industrial age. Basic objective of the economical and effective machining practice are metal removal rate, good surface finish, economy in tool cost, less power consumption, tool properties and tool life etc. nowadays the metal cutting process has become a very important material shaping process which is widely, used in automotive, railway, ship-building, aircraft industry etc., when we talk about the metal cutting the cutting tool plays a very important role, many researches and studies are going on to improve the quality & usage of the cutting tool. Cutting tool has to have certain aspects such as hardness, toughness & wear resistance. Commonly used cutting tool materials are High speed steel (HSS), diamond tools, abrasive tools, carbide tools etc., the ideal cutting tool materials should have characteristics like harder than the work it is cutting, high temperature stability, resists wear and thermal shocks, impact resistant, chemically inert to the work material and cutting fluid. HCHC steels contain 1.5 to 2.35% of carbon and 11 to 15% of chromium. These steels retain their hardness up to a temperature of 430 °C. Common applications for these tool steels include blanking or forming dies, thread rolling, die-casting die blocks, and drawing dies etc. forging with proper heat treatment `of HCHC steel it can be used as a single point cutting tool with improved properties as compared to high speed steel cutting tool.

II. Literature review

Nicolas et al. 2018 concluded that Ultraprecise single point inverted cutting (USPIC) is a microfabrication technique that has been recently developed for the generation of micro-optical microstructures with sharp concave geometries. Among the multiple challenges encountered during the micromachining process, tool alignment represents one of the critical factors affecting the overall accuracy of the microstructure that in turn affects its optical functionality. Since none of the presently available tool alignment techniques was found to perform well in the particular context of the diamond insert used in USPIC, an in-depth analysis of its mechanics was used in this study to provide insight on the interdependence between cutting tool misalignment and cutting forces. For this purpose, an experimental setup was devised to record the 3D cutting forces generated during the fabrication of two representative concave geometries delimited by planar facets. The first test geometry represents an instance of an isolated right triangular prism (RTP) whose quality and optical functionality will be significantly affected by diamond insert misalignment, particularly due to the undesirable contact to occur between the secondary/lateral cutting edges of the tool and the optically nonfunctional RTP facets. By contrast, the second test geometry had both lateral facets removed, such that the cutting conditions obtained in this case could be regarded as similar with that of the classical orthogonal cutting setup. Direct comparisons of the cutting force profiles obtained for the two cutting scenarios enable unequivocal identifications of tool misalignment direction and magnitude, such that targeted corrective actions could be performed to address the issue.

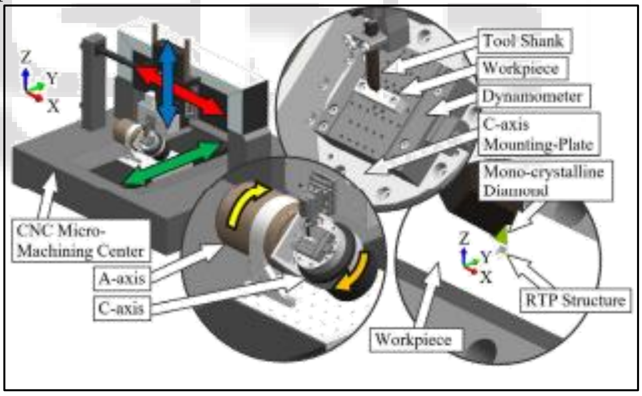

Fig. 1: Experimental Setup: Five-Axis Micromachining Center, Tool, Dynamometer, & Workpiece

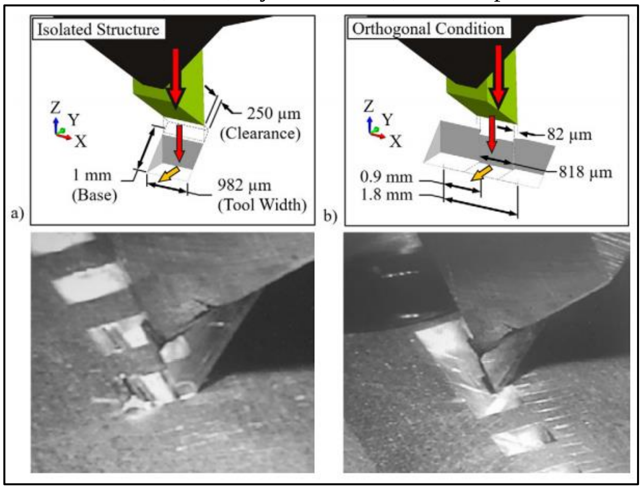

Fig. 2: Cutting Scenarios: A) Isolated, And B) Orthogonal

Bharath and shivshankar 2017 demonstrates the use of High Carbon High Chromium Steel (HCHC) as a single point cutting tool and also evaluated the properties at high temperature range (2000 C to 4000 C), HCHC tool find its applications in blanking or forming dies and thread rolling dies. The experiment results like hardness, tool force analysis using lathe tool dynamometer and tool life using Taylor's tool life equation are compared with HSS single point tool. The results shows that the forged and heat treated HCHC single point cutting tool performs similar to HSS tool and at high temperature performs better than HSS single point tool with higher tool life.

Zhang et al. 2019, studied the relation between centre error and interference force was investigated. A series of experiments were conducted to explore tool interference generation and its influencing factors. A mathematical model was derived to calculate the tool interference zone radius, whereby the relation between this radius and the cutting conditions was established. Moreover, the error sources between the theoretical and experimental results were analysed. As centre error can only be reduced by compensation and cannot be eliminated, particularly in machine tools with poor resolution, it is meaningful to conduct research on the centre cone generation and its influence on tool interference in SPDT, as well as suppressing the tool interference in SPDT. Furthermore, this research provides a reference for establishing an online force-based centre error identification method, thereby improving cutting efficiency.

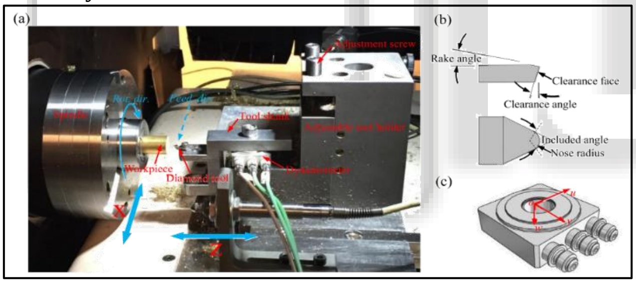

Fig. 3: (A) Experimental Setup, (B) Geometric Parameters of Diamond Tools and (C) Force Component Directions of the Dynamometer (Kistler 9252A)

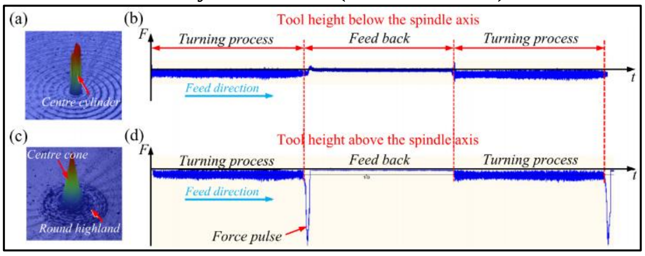

Fig. 4: Centre Cylinder and Cone Appearances and Corresponding Cutting Force Forms

Yuan et al. 2017 presents a method, which is referred to as the edge reversal method, is proposed for precision measurement of the cutting edge radius of single point diamond tools. An indentation mark of the cutting edge which replicates the cutting edge geometry is firstly made on a soft metal substrate surface. The cutting edge of the diamond tool and its indentation mark, which is regarded as the reversal cutting edge, are then measured by utilizing an atomic force microscopy (AFM), respectively. The cutting edge radius can be accurately evaluated through removing the influence of the AFM probe tip radius, which is comparable to the cutting edge radius, based on the two measured data without characterization of the AFM probe tip radius. The results of measurement experiments and uncertainty analysis are presented to demonstrate the feasibility of the proposed method.

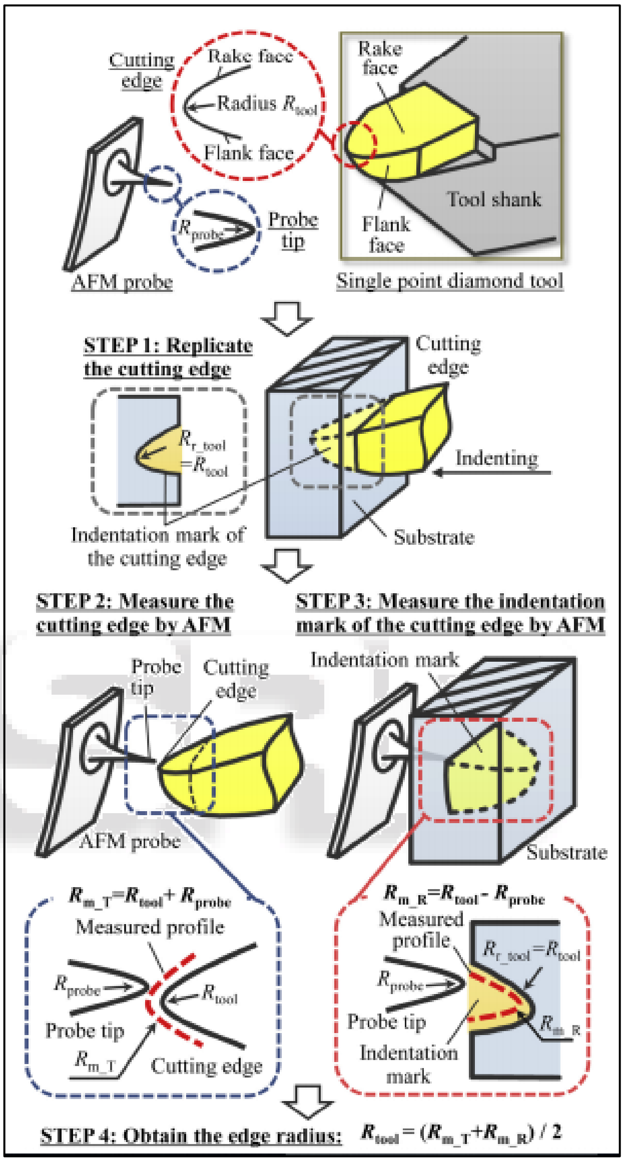

Fig. 5: Schematic of the edge Reversal Method Proposed for Precision Measurement of the Cutting Edge Radius of a Single Point Diamond Tool

Kolla et al. 2018 concluded that Cutting tool life is reduced remarkably in machining steel with High speed steel (HSS) tools at high cutting speeds and feed rates. Due to poor cutting characteristics with the uncoated HSS tool, tool life is short and good surface finfish cannot be obtained in many cases. Therefore, the cutting characteristics can be improved by using Physical Vapour Deposition (PVD) coated cutting tool. In the present study, HSS single point cutting tool was coated with TiN, AlCrN and TiAlN by PVD method (Derlikon Blazer Ltd.).The cutting characteristics of TiN, AlCrN and TiAlN coated tools are investigated by measuring cutting force and hardness.

In a study conducted by Aramcharoen et al. 2008 five different coatings (TiAlN, CrN, TiN, TiCN, and CrTiAlN) achieved by reactive closed field unbalanced magnetron sputter ion plating on 500 µm diameter ultra-fine grain tungsten carbide two-flute flat micro end mills has been investigated and their machining performances are tested during micromachining of hardened H13 tool steel with a hardness of 45 HRC. Their measurements revealed that TiCN has the lowest friction coefficient of 0.16, while the highest friction coefficient of 0.46 has been reported for TiN. For all coating materials, edge rounding and edge chipping has been reduced compared to uncoated tool. TiN has shown the best performance in terms of edge chipping and minimum flank wear, while delamination has been observed in CrN and TiC coatings.

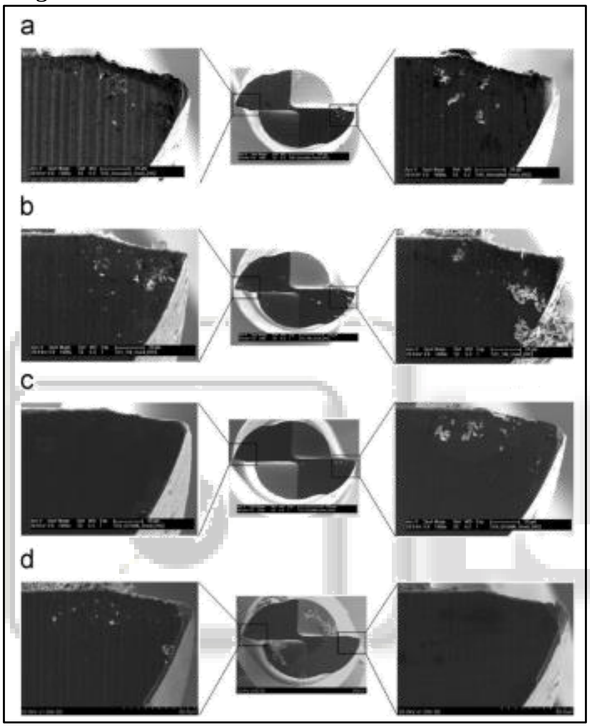

Fig. 6: Wear on Tool after Machining (a) Uncoated, (b) TiN, (c) CrTiAlN and (d) TiAlN

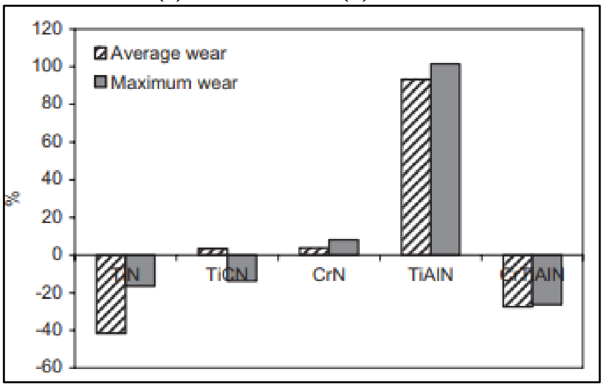

Fig. 7: Comparison of Wear between Coated and Uncoated Tools

Shivakumar Gouda et al. 2018 is mainly concentrated on the vibration and thermal study during cutting process on lathe. Extreme vibration happens in the machining environment because of a dynamic movement between cutting apparatus and work piece. In all the cutting processes, vibrations and temperature impacts are prompted because of the disfigurement of the work piece and cutting apparatus wear, so the motivation behind this present work was to research the impact of the cutting parameters on the temperature at the edge of the cutting apparatus. The temperature has been measured utilizing a test setup with thermocouple and the vibrational characteristics using vibrometer. Finally, the experimental results were simulated using finite element software ANSYS work bench 15. The results and conclusion from this work help to analyze the cutting tool behavior, to get good surface finish and prevent us from the improper selection of the cutting parameter.

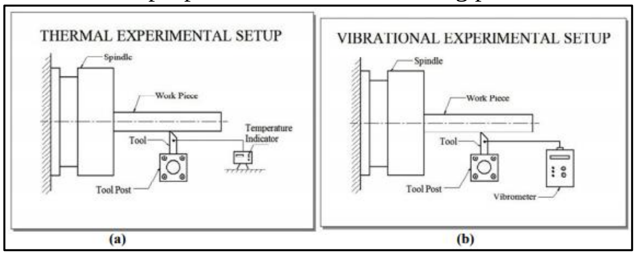

Fig. 8: Schematic Showing Experimental Setup (a) For Thermal Analysis and (b) For Vibration Analysis

In another study conducted by Kim et al. [8], a hybrid coating system which combines sputtering and arc ion plating (AIP) is used to deposit CrCN, CrSiN, and CrSiCN. A maximum hardness of 45 GPa has been achieved for CrSiCN coatings with silicon content of 9.2 at. %. Their results showed that during micromachining of brass with 0.2 mm micro end mill, CrSiCN and CrSiN have the best resistance to wear.

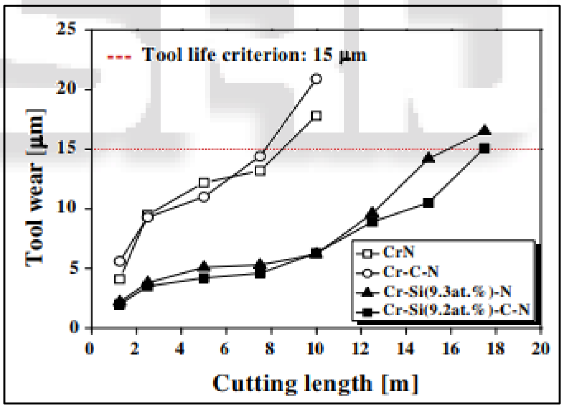

Fig. 9: Variation of Flank Wear of CrN, Cr–C–N, Cr–Si–N, and Cr–Si–C–N Coated Micro End-Mill as Function of Cutting Length

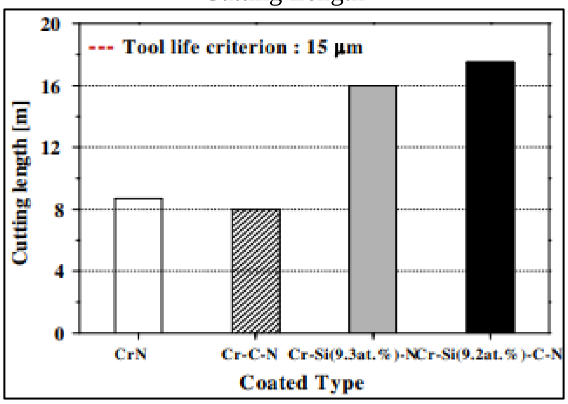

Fig. 10: Comparison of Tool Life According to CrN, Cr–C–N, Cr–Si–N, and Cr–Si–C–N Coated Micro End-Mill

Tadeusz et al. 2018 Development of machining process depends of cutting tools and machine tools. Various new tools are being developed and tested. For example special tools for oblique cutting or mechatronics tools. Oblique cutting process using special tools with continued cutting edge and high value of cutting angle λs make new possibilities to research. This tools characterized by single continued edge without the corner of the edge. Task of corner now have the current point of contact between the continuous cutting edge and the machined surface. Single edge tools exist with straight and circular edge. This tool are very useful especially for surface finishing In paper was presented many new solution of cutting tools for oblique cutting both with straight and curvilinear cutting edge with high value of λs angle (60°). Was developed both virtual models of this tools and its prototypes. CAD models are convenient for analyzing the geometry of these tools.

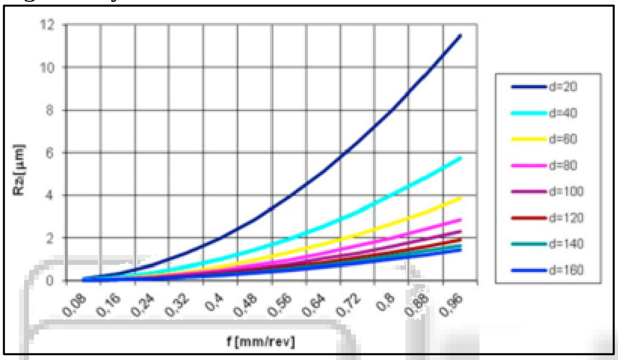

Fig. 11: Graphical form of Rzt value for Oblique Turning (λs=60o) with Single-Edge, Depending on the Feed and the Diameter of the Work Surface

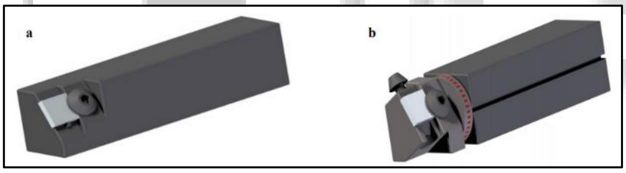

Fig. 12: MCAD 3D Models of Tools for Oblique Cutting with Straight Cutting edge: a) the Tool with a Permanent Geometry of edge, b) a Tools with Moveable cutting Edge with an Option to Change λRsR angle

Marcelo et al. 2019 presents a novel micro machining process as an alternative to other micro machining processes like micro milling. Its main advantage is the simplicity of the cutting tool geometry compared to other complex micro tools. The basis of this process consists of keeping the cutting tool always tangent to its trajectory. To achieve this goal, an innovative 6 degree-of-freedom parallel machine tool with high stiffness and with the tool tip precisely positioned, has been designed and built. The new machine is based on a hybrid device composed of three PRS (prismatic-revolution-spherical) parallel mechanisms with a linear XY stage and a C rotational axis. In order to determine the cutting load on the machine and consequently, its deformation, a resultant cutting tool force model has been developed which considers all the angles of the cutting process. A machining strategy has also been developed which takes into account the tool geometry and the kinematic restrictions of the machine tool. As a result of the kinematic and dynamic modelling of the machine, it has been possible to establish the level of precision for a given machining strategy. From the tests carried out, it is shown that the proposed machining process combined with the parallel machine tool, is an alternative to micro milling technology.

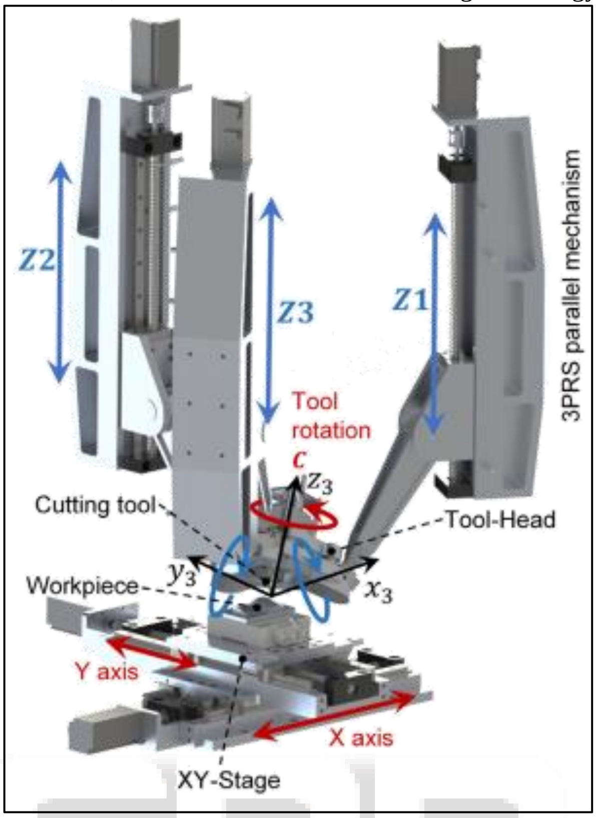

Fig. 13: Geometrical Model of the 3PRS+XY+C Hybrid Machine Tool

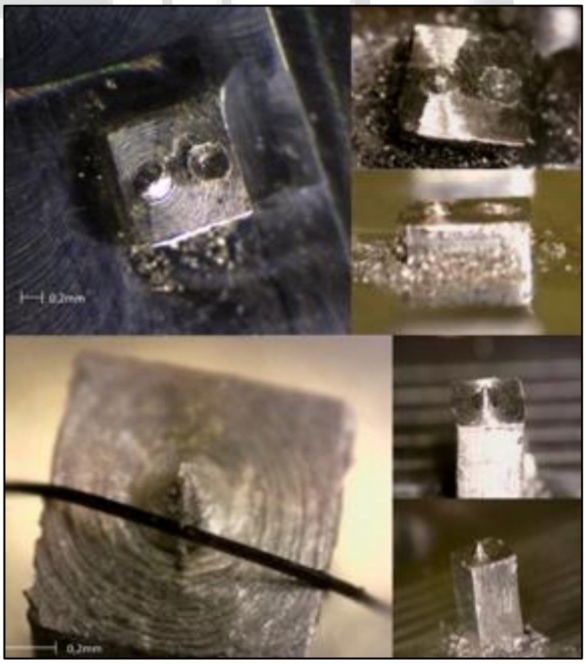

Fig. 14: Micro Geometries Obtained with the 3PRS+XY+C Micro Machine Tool. Top Image Shows a Concave and Convex Dome, the Bottom Image shows a Micro Cone Compared to a Human Hair

Butler et al. [11] exploited ND:YAG Q-switched pulsed laser system along with the indexing rotary stage and fabricated rotary solid grinding wheel made of polycrystalline diamond (Fig. 15). 36 staggered rows of the grinding tool were laser ablated by setting the rotary stage at 10° and with the help of Mastercam X that controls the laser path. Laser parameters used in this fabrication were output power of 100 W, pulse frequency of 50 kHz, lasing wavelength of 1064 nm and focal spot diameter of 40 µm [11].

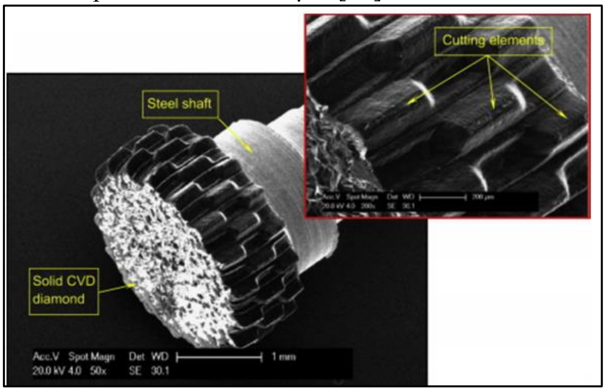

Fig. 15: Unused Laser Ablated Solid Diamond Micro-Grinding Tool [11]

Eberle et al. [12] demonstrated the laser technique to shape single cubo-octahedral shape diamond grains for engineering grinding tools (EGT) application. Fig. 16 shows the unmodified and modified diamond grain with the help of laser machining. For this purpose, an Nd:YVO4 diode pumped MOPA laser system with pulse duration of 10 ps is used. As can be seen from Fig. 23, both clearance and rake angle are fabricated in a single diamond grain which reduces the volume of the grain to 50%.

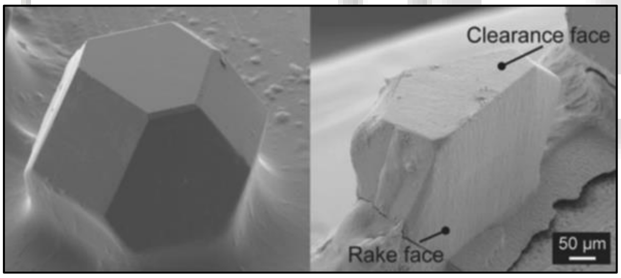

Fig. 16: Diamond Grain Shaped by Laser for EGT Applications

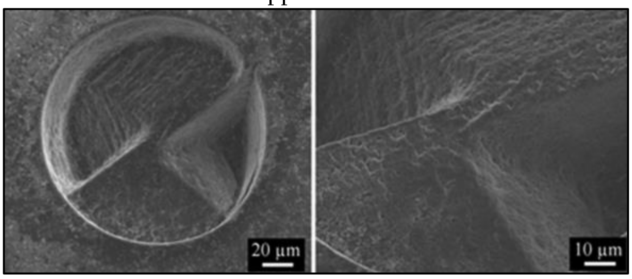

Fig. 17: Prospective Drill Bits and Close Up View

Eberle et al. [13] also fabricated drill bit of 150 µm diameter using picosecond laser where the chisel and cutting face are completed in one step. However, this process comes with discretization error such as steps which are quite noticeable from the Fig. 17. Finer Z steps size and objectives with higher numerical aperture could be a solution to get rid of this problem

Zhang et al. 2014. Presents a dynamic multiscale simulation based on quasicontinuum method (QC) has been conducted to study the effect of tool geometry in nanometric cutting process of single crystal copper. In the simulation, the many body EAM potential is used for the interactions between copper atoms in of the workpiece. The simulation captures the atomistic behaviors of material removal mechanisms from the free surface and the mobility of dislocations and their interactions with the computational cost of local atomistic simulation method. Simulations are performed on single crystal copper to study the atomistic details of material removal, chip formation, sub-surface deformation, and machining mechanism. The simulation results demonstrate that tool edge radius has significant effect on chip formation and subsurface deformation, because the effective rake angle varies with the tool edge radius. In addition, different effective rake angles result in different stress states and smoother surface can be obtained under bigger clearance angle. The variations of tangential force, normal force as well as the ratio of normal force to tangential force are obtained to analyze the effects of tool edge radius, rake angle and clearance angle in quantitative way.

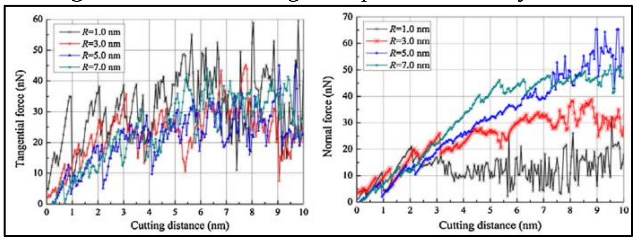

Fig. 18: Variation of the Cutting Forces with Cutting Distance for different Tool Edge Radius

III. CONCLUSION

- The lateral contact between the secondary cutting edge of the tool and the workpiece – that is in fact a consequence of the inappropriate tool orientation – is responsible for the generation of cutting force components that would be inexistent in the ideal/practically unattainable case of a perfect tool alignment.
- The forged & heat treated HCHC tool acquires all the properties of a single point cutting tool And It perform good machining operation at higher temperature with very less tool wear (i.e., tool tip blunt) and also perform better at higher feed rates. Due to the presence of more alloying elements the toughness of HCHC tool is higher compare to HSS tool.
- The cutting parameters have multiple effects on the tool interference zone caused by centre error. A reduction in the cut depth and centre error and increase in the tool clearance angle could reduce the tool interference zone radius and suppress the tool interference
- On comparing TiAlN AlCrN and TiN cutting tool TiAIN coated cutting tool experienced lower main cutting force compared to the other two coated tools, when cutting speed is varied where as AlCrN coated cutting tool experienced lower radial force compared to other two tools, when cutting speed is varied.
- Small rake angle causes increased stiffness and reduced tool wear, negative rake angle improves strength of cutting edge

- Larger neck angle, negative rake angle and optimized tool core geometry assist in better stiffens.
- Single edge geometry tool assists in proper adjustment of lateral infeed as well as feed per tooth.
- Have a high stiffness to reduce the amount of tool deflections and minimize the risk of chatter.
- Have sharp edges with elevated strength to avoid chipping, to reduce ploughing effects and improve tool life.
- Prohibit contact with the side walls of the workpiece having a flank geometry
- Turning operation with the lower speed and lower depth of cut showing rise in temperature of the tool tip is too small compared to the high speed and high depth of cut in both the tools and workpiece materials.
- The tool edge radius has significant influence on the nature of chips formation and the subsurface deformation as well as the variation of cutting forces, so the tool edge radius cannot be negligible in simulation of nanometric cutting.
- As the edge radius increases, the volume of scraps becomes smaller, the workpiece undergoes stronger compressive stress and the depth of sub-surface deformation increases. Besides, the tangential force decreases firstly and then remains stable but the normal force shows a dramatic increase with the increasing of edge radius.
- Different rake angles result in different stress states and bigger the tool rake angle taken, smaller is the scrap generated and more easily are scraps removed. As the tool rake angle increases from −8◦ to 8◦, both the tangential and normal cutting forces decrease considerably.
- Properly bigger clearance angles are beneficial to improve machined surface quality and reduce the sub-surface damage. Moreover, along with the increasing of tool clearance angle, the average value of tangential forces decreases but the normal forces show an obviously declining trend.

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