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A Review on Effect of Coatings on Tools and Surface Roughness as Vibration Resistance

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Abstract – Cutting tools in the machining industry are required to provide a level of mechanical strength and chemical stability such that they provide both durability and performance. The state of the art suggests that the mechanical requirements can be met; however, corrosion and wear requirements particularly in severe conditions. Most of the coatings were used widely in the industry to improve the wear resistance of surfaces in the machine elements. It has high hardness with superior chemical and thermal stability. The effect of coating systems on the tool performance when turning and milling is outlined in this paper. The interaction of wear and thermo-mechanical degradation of the coatings will be described by the characteristics of the non-metallic inclusions of the material grades and the balance of the flank and rake face wear of the CVD and PVD coatings. Coatings significantly influence the machining performance of tools by acting as thermal barriers and by enhancing the wear resistance. To model how coatings influence the tool loading, analytical and numerical approaches have been proposed to gain understanding on the effect of coatings on the tool temperatures. In this review paper, various coatings and its applications were considered from the various investigators and also vibration control methods study were analyzed.

Index Terms – Coating, wear resistance, tool life, surface roughness, vibration.

1. INTRODUCTION

Cemented tungsten carbide, WC-Co is the most common cutting tool inserts for machining of castings and alloy steels due high toughness and hardness. The performance of these cutting tools with regards to tool life travel path, the required power for machining, and the surface quality of the generated work pieces improves remarkably using coated cemented carbide cutting tools. Layers of titanium carbide (TiC), titanium nitride (TiN), titanium carbonitride (TiCN), titanium aluminum nitride (TiAlN), and aluminum oxide (Al2O3) are most commonly used when machining metals. The effect of these coating materials on the heat partition during machining and on the wear forms was partially analyzed in prior investigations. Carbide tools are coated with hard materials such as TiCN, TiAlN, TiCrN, and TiAlSiN to improve the cutting ability under high speed and high temperature TiCN coating is a solid solution of TiN and TiC which having a combine wear-resistant characteristics of both TiN and TiC . The superior tool life of TiCN coated tools over those coated with TiN can be attributed to the inclusion of carbon atom in the TiN lattice which results increase of the film hardness and lowering the friction coefficient. TiCN; TiZrCN; TiNbCN and TiSiCN coatings were comparatively analyzed for elemental and phase com- position, adhesion, anticorrosive properties and tribological performance at ambient temperatures. Zr, Nb and Si alloying contents in the coatings were good and the Ti based coatings with Nb or Si alloying elements proved to be resistant to corrosive attack in NaCl and of these coatings the TiNbCN was found to have the best corrosion resistance. TiNbCN coatings would be the most suitable candidate for severe service (high temperature, corrosive) etc. Tool wear mechanisms that are active during semi finishing is typically abrasion, adhesion, diffusion and chemical wear. Typical tool wear patterns include flank wear, crater wear, notch wear, thermally induced crack formation, edge chipping, edge fracture and plastic deformation. The active wear mechanisms and the generated tool wear patterns depends on the machining parameters and the properties of the selected cutting tool and work material.

1.1Benefits of tool coatings

A coating is a layer that is applied to the surface of a body, generally denoted to as the substrate. The coating may be decorative, functional, or both. The coating in the form of all-over coating, entirely layered the substrate, or it may shield parts of the substrate. The higher levels of performance can be made by the new and emerging coatings continue to improve material surface characteristics. Definable finishes, glossy appearances, perceptible feel, and slip/skid resistance. Barrier protection from moisture/oxygen transmission and grease migration is also rapidly evolving. New interactions are also presenting maintainable and renewable content. Bonding of these coatings is critical to show and establish the right surface treatment approach with experience in the following product platforms, coating processes. These coatings are used for nonstick purposes, corrosion resistant, abrasion resistant, friction resistant and chemical resistant etc., In general, coatings are classified in to metal and tool coating, ceramic, epoxy, polyester, polyurethane and hybrid coatings. PVD and CVD process of coatings are used in the scenario for various coating applications. Many researchers were done well in the coatings and its applications. [10]Surface of carbide inserts were treated with the wear resistant coatings were discussed by Vereschaka et al., here the new coating Ti-TiN-TiAlCrN (multilayer new composite coating) were introduced. It showed that the inserts with new coatings have higher wear resistant than the commercial ones for the depth of cut 4-8 mm. The cutting speed and feed rate is maintained 40-80 m/min and 0.8-1.2 mm/rev.

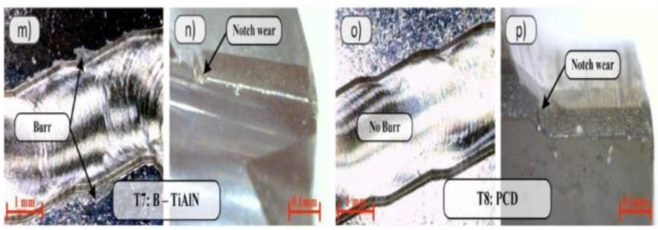

Fig.1 Burrs and tool wear effects with the considered tools

The operational life of the tool inserts with the elaborated coating exceeded by a factor 2. [11]Improvement of tool life by coated tool material were discussed by Marco Sortino et al., here better adhesion of coated molecules on work material by the initial set of tool materials. Instead of using this material A (AlCNN), TiSi, material B (TiCN, ZrN, AlCrN and TiAlN) coated over the surface of the milling cutter. Better performance was obtained by the material B Nickel silver coated tool material.

1.2 Improvement of tool life by wear resistance coatings

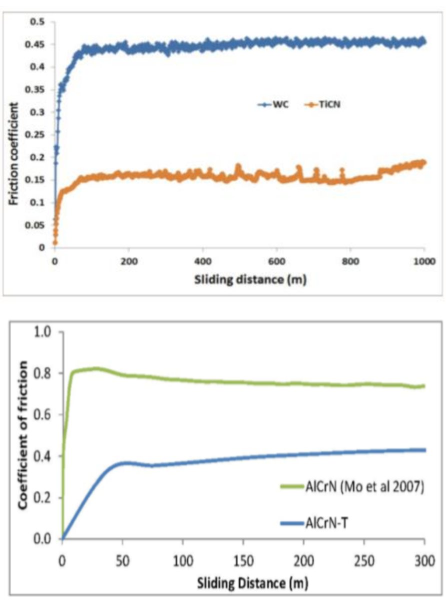

Fig.2 Coefficient of friction against sliding distance

Improvement in wear resistance of surfaces of the cutting tools, mould dies, aerospace components and machine elements, coatings were used in the tool surface in the combined form of TiN and TiC. TiCN is mentioned in this work by R.J. Talib et al., The turning operation were performed over the specimen at the speed of 60mm/min, feed rate of 0.06 mm/rev and depth of cut 1 mm. coated and non-coated tungsten carbide insert and WC tool were used and the flank wear and the tool life was evaluated.

Less flank wear 1.31 mm was measured in TiCN coated tool and high value 1.43 mm was occurred in WC tool. TiCN coating has lowered the coefficient of friction as compared with uncoated tool as shown in figure 2. The major benefits were identified as increase of film hardness and lowering the friction coefficient. The reason behind this is the formation of graphite particles on the surface leads to reduce the coefficient of friction in the coated tool insert.

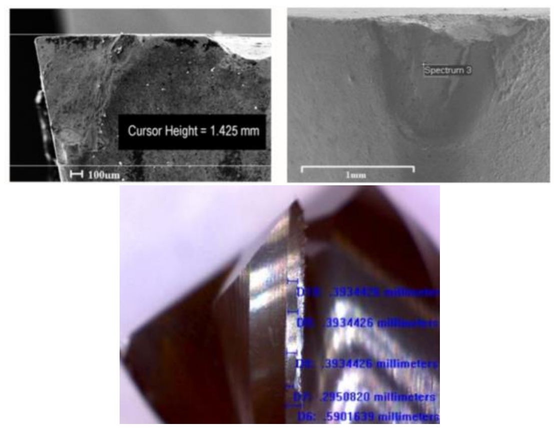

Fig.3 Tool wear patterns on (a) Catastrophic failure of WC insert, (b) TiCN coated (c) AlCrN-T coated

The test results showed that the tool life of TiCN coated insert is 42 minutes as better compares with the WC tool were 4.5 minutes. Hence more tool life was achieved during the usage of coated tool insert. [3] Hector et al., discussed about the efficient machinability tests on Ti6Al4V alloys with heat treated mono layer AlCrN coating, competitive with other coatings in the machining of titanium alloys were analyzed. The coefficient of friction and tool wear rate corresponding to the sliding distance the less values were recorded for the heat treated AlCrN coatings as shown in figure 2. It was revealed that the AlCrN-T coating has a wide potential tribological application under the condition of sliding wear. [4]The tool performance during the turning operation of 4140 steel specimen by using coated cemented carbide tools were discussed by Jan C. Aurich et al., as shown in figure 4. Remarkable differences in terms of tool life travel path were observed. Five different types coated and non-coated tool inserts were used for the betterment of turning operation as well as tool life. Different layers of coated tools were used here in this work. TiN-TiCN-Al_2O_3-TiCN layered tool insert were performed well by giving longest tool life travel path.

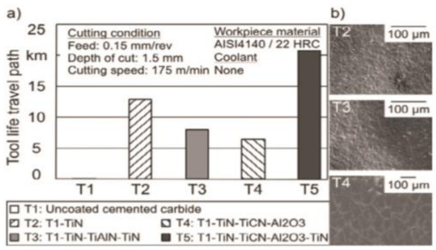

Fig.4 (a) Tool live travel path, (b) Coating surfaces prior cutting

Lowest tool life by TiN-TiCN-Al_2O_3 the layer of Al_2O_3 leading to flank wear and it is flaked and cracks are clearly observed. Due to TiCN layer having greater hardness of this layer leads to a remarkable flank wear. Low abrasive wear resistance of Al_2O_3 layer and low thermal insulation of TiCN layer lead to a minimal tool life of all investigated coating systems. The uncoated cutting tools showed the tool life travel path of 0.18 km, whereas the tool life ranges from 6.4 km to 20.8 km using coated indexable inserts. By far the longest tool life travel path is achieved by the indexable inserts with the multilayer coating system TiN-TiCN- Al_2O_3-TiN. Remarkable differences regarding the tool life travel path are observed. [5] Identification of flank and rake face wear on 20NiCrMo steel specimen by using Chemical Vapour Deposition (CVD) Al_2O_3 TiN coatings were discussed by Niclas Ånmark et al., The cemented carbide tool coated with multi layers of Al_2O_3 and TiCN. Here they inspected that the stress raises in the shear zone and easy chip formation. The interaction of abrasive wear and thermo-mechanical degradation of the Al_2O_3 upper layer was described.

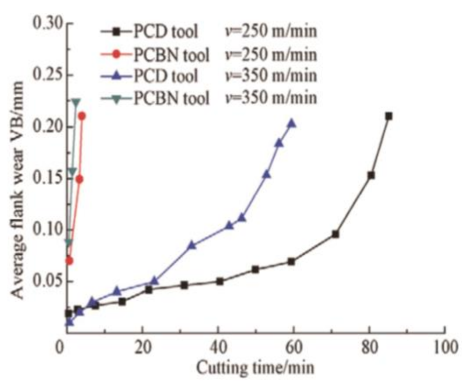

Fig.5 Average flank wear of Polycrystalline tools

The results showed that the abrasive wear had progressed further when machining the clean steels C and ultra clean steel in comparison to machining standard steel R. Also, machining the UC indicated a faster abrasive wear than clean steel C. This was observed by the exposed mean width of TiCN on the rake face crater of the cutting tools. The superior machinability of the reference steel grade R is linked to its high content of non-metallic inclusions and foremost MnS inclusions. Non-metallic additions act as stress raisers in the shear zone. Thus the chip formation was normalized and become easy.

[20]Performance and wear mechanism of the tools were investigated by SU Honghua et al., Polycrystalline Diamond (PCD) and Polycrystalline Cubic Boron Nitride (PCBN) tools were used here for machining of TA15 alloy. PCD has much longer tool life at higher cutting speed than PCBN cutting tools. Oxidation wear was observed at PCBN tools.

The tool failure occur because of average or maximum flank wear, crater wear depth and breakage or fracture. Non uniform wear was observed on both tools. Notch wear in PCBN tool arises from the combination of high temperature and high cyclic stresses and adhesion of titanium work piece onto the PCBN tool during the cutting process.

Milling by PCD and PCBN tools with high coefficient of thermal conductivity and low friction coefficient and cutting temperature used to induce any phase transformation and also this implies that no thermal damage occurred at the milling conditions. [21]The effect of tool wear on Nickel based alloy Inconel 718 material were analyzed by W. Li and Y.B. Guo et al., in end milling process. Surface roughness, microstructure and micro hardness were evaluated as shown in figure 6. Surface finish was occurred in between 0.1 – 0.3 µm.

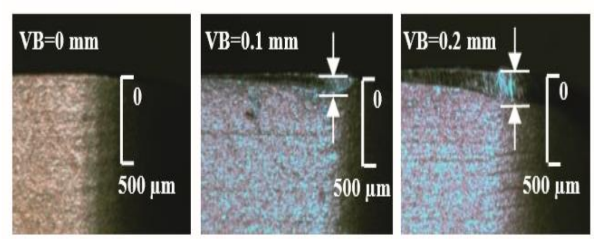

Fig.6 Microstructure of tool wear

Tool wear was measured by an online optical tool inspection system (Fiber Optic Illuminator). Here 4 point bending fatigue test was used to determine the fatigue life of the work piece. Higher tool wear produced less surface roughness was proved and no fatigue occurred up to the cutting speed 0.2 mm/min. Tool wear with in the certain limit doesn't affect the fatigue life.

2. EFFECT OF COATINGS IN SURFACE ROUGHNESS

Increasing of cutting tool edge radius of 2.5 to 2.9 µm for higher processing time leads to decrease the tool wear was discussed by Y. Kuche et al., if the cutting edge radius is growing, the tool wear was increased. They referred that the surface roughness improvements were made completely based on cutting edge preparations.

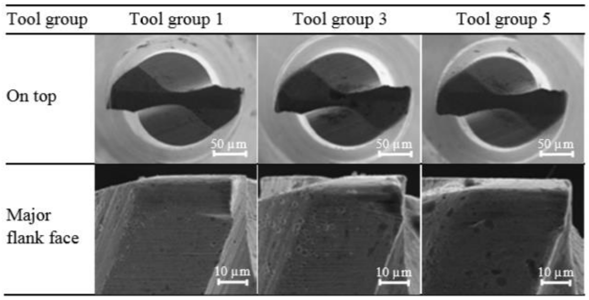

Fig.7 SEM images of the tool wear

In this experiment they used two fluted end mill cutter made up of cemented carbide with the diameter of 0.5 mm as shown in figure 7. [19] In the view of improving surface finish and frequency response function, three different tool holders were used in various lengths by E. Hasselberg et al., based on industrial applications, material properties, hardness and tensile strength, Al, CI and Polyurethane obomodulan specimens were chosen for machining.

Fig.8 Milling of Polyurethene, Cast Iron, Aluminium materials by varying length shrink fit holders

Thl120 holder has short length is the significant influence on the surface shape and also achieved good surface finish. Frequency more observed in this short length tool holder. Compliance (G) becomes low in high length tool holder thl200. [20] SU Honghua et al.were investigated the Surface roughness values with PCD/PCBN tools are below 0.3 µm is observed. Surface roughness was so good nearly 0.2 µm in PCD tools. Plastic deformation on the machined surface is caused by the high cutting pressure at elevated temperature during the machining process due to low thermal conductivity.

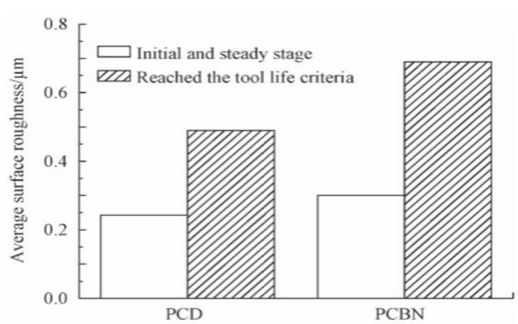

Fig.9 Comparison of surface roughness among PCD and PCBN tools

Electrical Discharge Machining (EDM) was done to improve the surface finish values based on the Metal removal rate among the TiCN work piece and Cu electrode by Feng Yerui et al., The increase of peak current, the SR and MRR increases gradually because of the singe pulse energy increases. Due to the increase of pulse duration, surface roughness and MRR was increased.

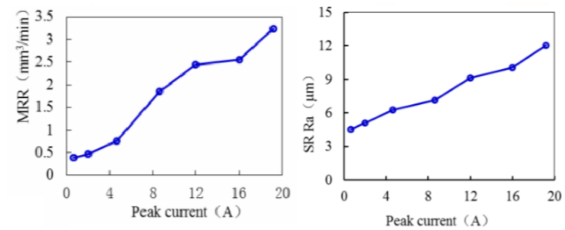

Fig.10 Metal removal rate and surface roughness in EDM for the peak current

Metal removal rate decreases when pulse duration increases above 30 µs and SR increases slowly. They reviewed that the grain removal of TiC occurred by the gasification of Ni and TiC with the little influence of thermal stress.

3. EFFECT OF COATING IN THERMAL SHIELDS

Ivan Krajinović et al., were discussed that the hard coatings improves thermal shields. Three different types of Chemical Vapour deposition CVD coatings were preferred in this work. TiAlN, TiCN/Al_2O_3 bilayer coatings. A reduction of the plastic strain in the substrate is regarded as an important factor for a longer tool service life.

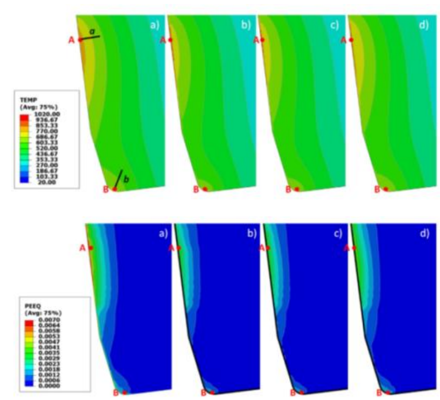

Fig.11 temperature field and equivalent plastic strain field in the uncoated and coated tools

The TiAlN and TiAlN/α- Al_2O_3 coatings behave as the best thermal shields of the coatings compared within this study, lowering the temperature in the substrate the most. Multiscale finite element modelling of milling were discussed regarding the temperature distribution among the tool and the specimen as shown in figure 11. Temperature, stress and strain fields were evaluated. The surface temperature of the rake face is the highest for the tool coated with TiAlN/ Al_2O_3. The analysis results showed that the surface temperature was calculated as high. Lower thermal conductivity leads to good thermal shield. The best thermal shields of coating is TiAlN/ Al_2O_3. [7] Turning operation of EN31 alloy steel with TiN+Al2O3+TiCN coated tungsten carbide tools was done for achieving better surface finish with reduced power consumption by Harsh Y Valeraet al., Three different parameters speed, feed and depth of cut were used as input parameters for getting output parameters of surface roughness and also power consumption through energy meter reading.

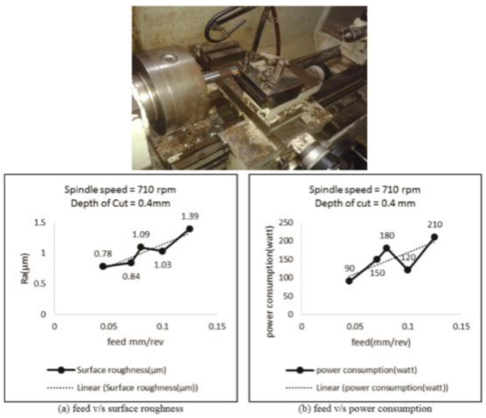

Fig.12 Coated carbide tool setup and the effect of variation of feed rate on Ra and power consumption

In this experiment, for 710 rpm spindle speed good surface roughness was achieved in the corresponding feed rate of 0.08 mm/rev. The depth was 0.4 mm respectively. They concluded the research paper which Increase in speed reduces the surface roughness value, while increase in feed and depth of cut reduce the surface roughness values. Power consumption is detected to be increased when speed, feed rate and depth of cut is increased. Hence, cutting speed is observed as a critical cutting parameter, which improves surface finish, when it is increased in value.

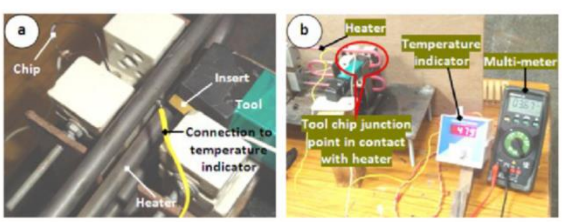

Fig.13 (a) Chip tool junction point in contact with heater (b) Calibration set up

It can be concluded that spindle speed, feed and depth of cut knowingly affect the surface roughness and power consumption while tuning EN 31 alloy steel work material using coated carbide cutting tool. [8] Chip tool interface temperature has minimized while using PVD coated (TiAlN) tool with respect to feed rate, depth of cut and speed as shown in figure 13 by Satish Chinchanikar et al., The cutting speed and feed are the most influencing parameters to modify the cutting tool interface temperature. PVD coated tool has more prominent compare with CVD (TiCN/Al_2O_3/TiN) coating to give low interface temperature hence proved by the experiment. [12] Niclas Anmark et al., were discussed the Hard turning of Ca rich inclusions machined by Polycrystalline Cubic Boron Nitride (PCBN) tool, based upon the machining flank wear and crater wear were determined by using scanning electron microscope (SEM).

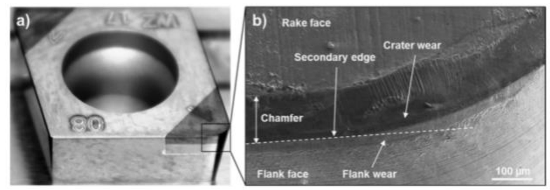

Fig.14 Overview of PCBN edge and tool wear

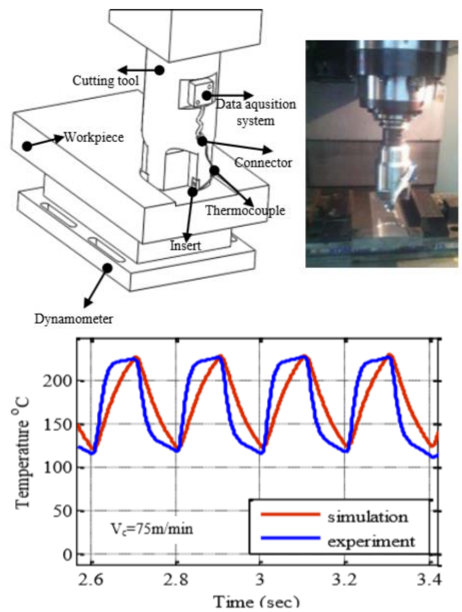

Fig.16 Comparison of simulation and experiment temperature measurement

The experiments were carried out in the cutting conditions of 166 m/min cutting speed, feed rate 0.24 mm/rev for the depth of cut of 1 – 1.5 mm after completing the carburizing, quenching and tempering for 2-5 hours. The R steel (EN19MNVS6) and M steel (Mn, Ca) S-(Al, Mg) grade were used as the specimen. They concluded that the machining time was saved in R steel work piece machining not in M steel, same time surface finish was good when the machining time was more. Tool life found good in the form of flank and crater wear in R steel machining because of less machining time. [17] The new experimental technique Novel method were used by Umut

Karaguzel et al to measure the transient tool temperature with K type thermocouple at the cutting speed of 50 m/min. It is used measure heat flux for identifying the temperature.

Here the effect of convection is negligible under dry conditions. Temperature distribution of cutting zone in milling operation is measured. Prediction is easily match with the measurement results as mentioned in figure 16.

4. VIBRATION RESISTIVE METHODS IN MACHINING

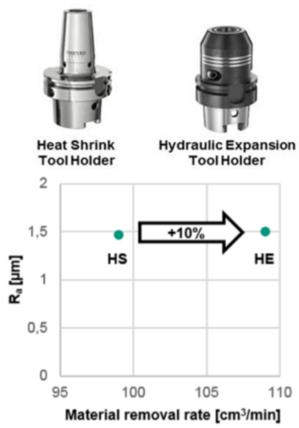

Fig.17 MRR and Ra comparison of heat shrink and hydraulic expansion tool holder

[13] Two innovative technologies in tool holder manufacturing Heat shrink (HS) and Hydraulic Expansion (HE) by Rothaupt et al., HE has higher damping rates than HS by showed the results of better surface qualities because of the clamping elastic deformation by fluid pressure as shown in figure 17. 300% higher achievable life time of tool by using Frequency Response Function (FRF). At above 1700 Hz, HS shows higher amplitudes than HE that is 4 times higher than HE amplitudes. HE has better damping properties than HS, so better surface roughness was obtained on the machined parts and it was produced well-structured surface and inordinate surface in HS. Tool life was saved due to minor flank wear by using hydraulic expansion tool holder. [14] Chatter prediction and effective implementation by RCSA approach on tool holder assembly for predicting the stability in milling by Niccolo Grossi et al., Collet chuck, shrink fit and hydraulic chuck were involved here for the experimentation.

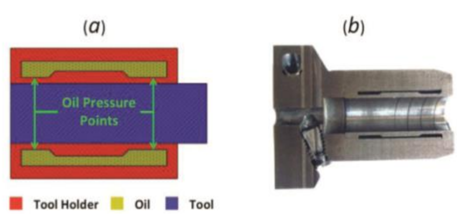

Fig.18 (a) Hydraulic holder working principle (b) real component cross section

Reacceptance Coupling Substructure Analysis (RCSA) implementation in hydraulic chucks showed higher accuracy model. It's a good chatter prediction implementation. FEA modelling of tool holder tool connection were obtained simultaneously. Comparison were made at the end between experimental, beam and solid model natural frequencies. Bases on results predicted FRF's and experimental data beam modelling provides accurate results for shrink-fit toolkits.

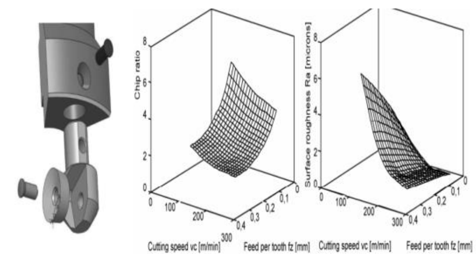

Fig.19 Chip ratio and surface roughness results of centrally positioned milling insert RCKX

Marek et al., were discussed about the safety and performance of milling cutters with shank style holders of tool inserts. Two modules were used RCKX (80-100 N) and OCKX (Max force). If the cutting force is greater than 5000 N are disposed to damage socket head screws and shank style insert holders. Combination of experimental testing and FEM studies have been used to identify both process capability and operation safety of newly designed milling cutters. The very advantage of such design of milling cutters is that no damage of tool body appears in heavy duty operations. If any damage occurs, usually a change of shank style insert holder is needed.

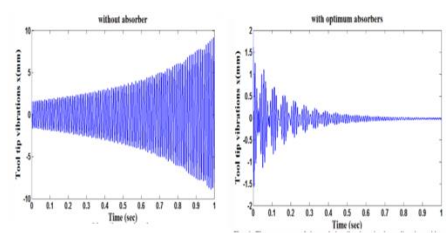

Fig. 20 Tool tip vibrations with and without absorbers

The unwanted oscillations of dynamic body to be suppressed by using Tunable Vibration Absorbers (TVA) by considering the mass and stiffness. Here vibration amplitudes are minimized as many as possible based on both time and frequency domains. It called regenerative chatter behavior was discussed by Navid Asmari Saadabad and Hamed Moradi. The regenerative chatter dynamics is formulated through delay differential equations and tuneable vibration absorbers are designed in two directions to suppress the unwanted oscillations. It is clearly shown that tool wear and process damping show a significant role in steadying the chatter process. However, according to the results, vibration absorbers stabilize the chatter process over a wide range of chatter frequencies in a global manner. [22] The effect of machining parameters on surface roughness and tool vibrations has evaluated by K. Arun Vikram et al.

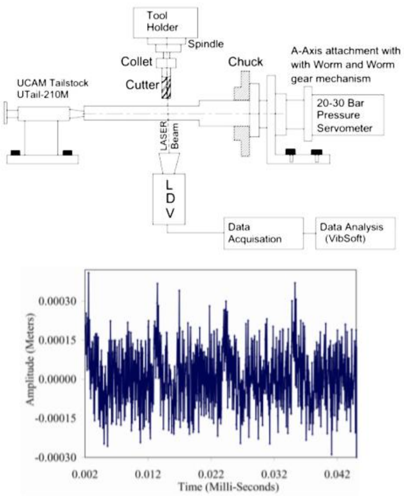

Fig.21 LDV setup and time wave form in tangential turn milling using carbide cutter at 5500 rpm

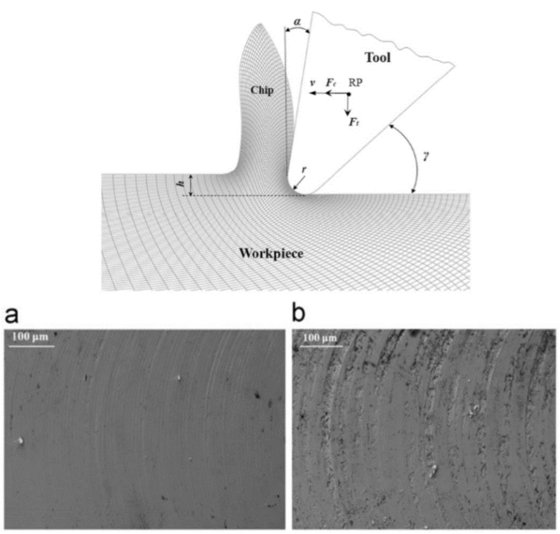

Fig.22 SEM images of orthogonal cutting with (a) no chatter marks (b) chatter marks

By using laser Doppler Vibrometer (LDV) the analysis of vibration are calculated through data acquisition and analysis method. In this experiment the tool displacement increases with depth of cut as well as the tool speed increases surface finish. Optimal values of surface roughness and displacements in tangential turn milling compare with orthogonal turn milling. Wherever the displacement is high poor surface finish was occurred. Similarly good surface finish is achieved due to less displacement. [23] Non linearity of the cutting forces caused mainly by the run out, cutting edge radius and cutting velocity were described by S.M. Afazov et al., Here in this experiment, SEM inspection of milled AISI 4340 was conducted for the identification of chatter marks in the machined profiles.

By increasing the run out length, the stability lobes move in the spindle speed axis and the stability area decreases due to higher cutting forces. Dynamic Finite Element Analysis are performed in ABAQUS for prediction.

5. CONCLUSION

Based on the research reviews it is concluded that the coated inserts and tools gave significance improvement in their machining and tool properties. The tool wear is minimized completely by coated tool tips and inserts. Tool life is getting more in Titanium based coated tools because of high corrosion and wear behavior of material therein. Low coefficient of friction was occurred due to the usage of TiCN coated tools. Poly Crystalline Diamond has much longer tool life at higher cutting speed than Poly Crystalline Boron Nitride cutting tools. In both PCD and PCBN cutting tools the surface roughness were achieved well compare with the uncoated one. The bilayer coatings with TiCN through CVD is an important factor for a longer tool service life as well as PVD coated tool AlCrN has more prominent than the CVD proved by some previous experiments. So coatings were plays an important role for improving the tool life and surface quality. In addition, the geometrical changes were made on machine components will cause some deviations in machining parameters. RCSA and hydraulic chuck model showed higher degree of accuracy and good chatter prediction methods. The negligible oscillations of active body to be inhibited by using Tunable Vibration Absorbers (TVA) and LDV methods. So the vibration resistances were installed and acting as intelligent methods.

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