Experimental Investigations of H-13 by using different Coated Tools

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Abstract - *This paper presents a new concept to develop a cutting tool for milling technologies. To enable milling for HDS H-13 material for heavy extrusion and forming tools and dies, a milling tool is a key factor. The tool is consisting of a monolayer coating of TiAlN and innovative coating system consisting of AlCrN - TiAlN Bi-layer. By using the said composition we study the effect on surface roughness and tool-chip interface temperature while performing machining of HDS H13 material under wet machining condition. The machining experiments involves of a tool which is Bi-layer coated made up of carbide, carried at various parameters such as cutting speed, feed and cut depth under wet conditions. Optimum parameters of the process can be found using taguchi method. It has been discovered from results that machined material's surface roughness and tool-chip interface temperature is greatly contributed by the cutting tool type as a significant factor.*

Key Words: Carbide Tool, TiAlN monolayer, AlCrN-TiAlN Bi-layer, HDS H-13, Tool-chip Interface Temperature etc.

1.INTRODUCTION

Milling tool technologies is a main and key factor for cutting materials from hard metals. Tools and dies which are made of hard metals which are having higher hardness range are difficult to remove material from them. Basically these materials are machined by Non-traditional machining methods. But distinct tooling material and some different coatings combined used then the materials which are difficult to cut materials can be machined easily. Today, most cutting operations are conducted with different coated tools. Tool failures are guided by harder material's milling because of the fragmentation of the cutting edge's breaking or coating after short cutting travels. To reduce such and to increase tool life with greater surface finish, this paper presents a solution for machining hard metals or difficult to cut materials using different coated tools made up of tungsten carbide material. Coatings utilized in the cutting tools' surface engineering played extraordinary part in current betterment of harder cut material's high performance machining, mainly hardened HDS H13 tool steel. Machining using coolant or wet situations generally utilized on production area because of various issues. With difficult to cut materials' implementation in manufacturing practices an effective safeguard is needed by cutting tool from cutting zone's mechanical and thermal loads. Particularly, it is significant for wet conditions where tool life is greatly dependent on the thermal fatigue. When coatings applications are used it results in automatic enhancement in cutting tools' overall wear resistance as well as more significantly the machining process' productivity. So, coated tools' life must be studied with considerable attention as well as figure out these severe machining conditions' failure mechanisms. For steels' end milling various PVD coatings were developed which are hardened. For such application most encouraging are AlCrN-based coatings with minimized thermal conductivity, higher micro-mechanical properties and high hardness as well as AlTiN with high fatigue fracture resistance. This paper mainly focus on a) determining micro-mechanical characteristics set that has responsibility of cutting tools' wear behavior under disrupted cutting's heavy loaded conditions that are distinctive for hardened HDS H13 end milling, and b) for end mills analyzing failure mechanism (chip and wear formation) under hardened HDS H13 tool steel's wet high performance machining. In such manner, for particular application coatings selection are confirmed.

1.1 HDS H-13 (Hot Die steel)

High hot-wear resistance and hot durability and better thermal fatigue resistance, toughness, in accordance with plastic deformation, hot wear and hot cracking were cooled to a limited amount. H13 alloy steel may be adaptable hot work steel of chromium-molybdenum which is widely used in tooling applications of cold work and hot work. Due to the cooling and heating cycles results in the applications of hot working thermal fatigue cracking occurs. This paper analyzed that AISI HDS H13 steel tool is mixture of wear resistance and high-temperature strength. Its applications are used in pressure die casting, cold and hot forging and extruded tools. Anyhow, there exists a challenge in developing the HDS H13 tool steel molds and dies' high performance machining in a hardened phase. The hardened tool steel's machining conditions under high performance; cutting tool's mechanical characteristics are sturdily reduced by cutting zone's increased temperature. There is adequate increase in wear rates' of tool that resulted in impaired surface integrity and short tool life. Thus, machining operations' optimization is constitutional when dies and molds as well as H13 tools' production costs is significant. It resulted in machining efficiency's enrichment. Surface engineered tooling's application, specifically carbide tool with various PVD coatings is an effective way of achieving machining process's higher efficiency.

1.2 Characteristics of the coatings

The utilization of below coatings were done: AlTiN PVD coating as well as AlCrN-dependent coating (AlCrN–TiAlN bilayer and AlCrN monolayer). An AlCrN practical layer is placed on the shielding layer of TiAlN in AlCrN–TiAlN bilayer coating. A good mechanical strength and adhesion is endured by the TiAlN layer while low thermal conductivity, high hardness and good oxidation resistance is exhibited by AlCrN layer.

2. Literature Review

In various manufacturing fields, dies and molds has an increased demand. Under operating conditions because of the hardened tool steels' high performance, they are greatly used in molds and dies' casting and forging. Although, mold and die machining is a valuable and time consuming process. Conventionally, molds were manufactured by the grinding and EDM (Electrical Discharge Machining) processes. Although, surface damaged layers are created by both methods and EDM has relatively low material removal rate. Moreover, higher manufacturing cost is resulted due to their drawbacks. Additionally, at the core as well as cavity, several 3-D freeform face are contained by the molds and dies that have some difficulty in machining with grinding and EDM processes. Thus, there's an importance to create alternate systems to get over the disadvantages. Recently, hardened state H13 immediate milling was initiated to be utilized as a reasonable semi finish as well as finish procedure. This's because of the tool materials improvement has capability of milling hardened tool steels. Dies and molds' machining in a hardened status might be faster and cheaper compared to conventional techniques. Additionally, it has some other benefits, like part distortion removal triggered by heat therapy. AISI H13 tool metal has a mix of wear resistance as well as high temperature strength. It's been commonly used in pressure die casting, hot forging and extrusion mandrels. Although, H13 tool steel made dies and molds' high performance machining is a challenge in a hardened state. Coatings utilized in the cutting tools' surface engineering played extraordinary part in current betterment of harder cut material's high performance machining, mainly hardened HDS H13 tool steel [1].

In continuous cutting operations, tungsten carbides' general machinability has been shown by the more than15 vol-% cobalt content with coarse grain sized and turning fine grain sized tungsten carbides in the primary examinations. But because of the tool's continuous changing engagement condition as well as interrupted cut with the work, these results are not transferred directly to milling [2].

Surface roughness on the Al/SiC PMMC end milling by utilizing end mill cutters of TiAlN coated carbide. It has been discovered that in each case under study, the increase in feed rate results in increasing surface roughness. When these is an increase in the feed rate, then it resulted in increasing the chip thickness which resulted in cutting force enhancement. Furthermore, value of surface roughness is increased. Additionally, it has been noticed that increasing cutting speed decreases the surface roughness. When there is increase in cutting speed, it resulted in more adiabatic machining as well as during very short time interval when materials passed from this zone, shear zone generated heat can't be directed away. At that time, material supporting the dislocation of grain boundary is softened by rising temperature as well as value of surface roughness is reduced [3].

Coatings based on AlCrN have a selection of helpful qualities for tough conclusion milling circumstances, for example smaller winter conductivity and increased great hardness as when compared to AlTiN. Along with the attributes the tribo film development additionally plays job that is crucial of the enhancement in tool daily life. As a result there's a synergistic effect - advantageous AlCrN grounded coatings micro mechanical as well as actual physical qualities along with helpful tribo films development lead to improved practice balance as well as put on performance during damp machining of H13 [1].

In continuous cutting operations, tungsten carbides' general machinability has been shown by the more than15 vol-% cobalt content with coarse grain sized and turning fine grain sized tungsten carbides in the primary examinations. But because of the tool's continuous changing engagement condition as well as interrupted cut with the work, these results are not transferred directly to milling. It has been demonstrated by the earlier examinations on hard metal coatings' finishing that there exists carbide materials of milling tungsten feasibility with PCD (Polycrystalline Diamond) tool that has smaller range of parameter. Assessments had been carried out at the covering components WC17Co having 1100HV hardness. The coarse tool use on the flank facial skin showed a linear actions. In addition, with increasing chip thickness the top edge was subject to chipping because of the brittleness of the PCD. This use mechanism involves decreased procedure dependability. Because of the comprehensive expenses of the milling tool just small effectiveness may be gotten to. Hence, brand new milling application principles have to see reliable and profitable machining. Very first potentials of the application of coated carbide end mills in completing tough metallic might be revealed in an essential analysis. Nevertheless, chipping of the covering on the tool rake facial skin implemented by an impulsive disaster of the coating on the flank face lead to very low practice dependability regarding tool daily life as well as area quality of the efforts portion. Additional investigations were completed in the area of micro milling with CBN and PCD tool. They proved that ductile sawing of tungsten carbides can also be possible. The ductile-brittle material removal process area is described by setting up an analytical model. It has been discovered that tools have failed primarily due to cutting edges' breakages and chippings as well as has short tool lifetime. In addition to this, during the cutting of hard metals, mechanism of chip formation is investigated by ARIF [2].

HREELS (High-Resolution Electron Energy Loss Spectroscopy), electron spectroscopy techniques: XPS (X-ray photoelectron spectroscopy) and HRTEM (High-Resolution Transmission Electron Microscopy) were used for investigating the Nano dispersed (Ti10Al70Cr20N) and (Al67Ti33N) PVD Coatings' electronic structure and microstructure. HRTEM measured the Al67Ti33N and TiAlCrN coating's grain size that was 5–20nm. Al supersaturated nitrides' spinodal decomposition was discovered under its deposition. In c-Ti1_ xAlxN, h-AlN's metastable solubility is increased by chromium. Furthermore, Al-rich coating cutting tools' lifetime is assessed under aerospace materials and hardened alloy steel H13 (HRC 50–52) ball nose end milling. For aerospace material processing, AlTiN coatings are better, and for steel machining, TiAlCrN coatings are preferable. It has been noticed that AlTiN coating possesses improved impact stress fracture resistance, higher plasticity but low hardness. Whereas, at high temperatures, far better oxidation stability and hot hardness is possessed by TiAlCrN, but in comparison to AlTiN it is stiffer [4].

The phase stability of supersaturated c-AlxTi1 _ xN is based on coating's vacancies and atoms distribution along with chemical composition. h-AlN phase's solubility limit is increased in the complex nitride by Cr integration in metastable Al-rich c-Ti1 _ xAlxN matrix. In h-AlN inclusions, ion vacancy content of nitrogen is increased whereas ion vacancies concentration of heavy metal matrix reduces in TiAlCrN PVD. AlTiN coating possesses higher plasticity but lower hardness. Whereas, at high temperatures, far better oxidation stability and hot hardness is possessed by TiAlCrN and is stiffer. Coatings' service properties are controlled by the mixture of these physico- mechanical and structural characteristics [4].

The cutting tool's technology is quickly improving and this particular improvement is actually essential to enhance the use opposition as well as functionality of machining on difficult-to-cut substances. Enhancement in overall performance may be accomplished by raising the sturdiness of the cutting tools in phrases of put on opposition. Covering engineering is actually 1 of almost all crucial means of raising the machining functionality of cutting tool. Recently, the inclination towards covering engineering has grown with the expansion of slicing quickness as well as feed fee. Cementite carbide cutting tool are actually coated utilizing 2 various techniques [5].

Ceramics & hard metals are actually main substrate substances for a great assortment of cutting tool and being created expires. Due to the high certain hardness of theirs the supreme component geometry is generally received by preformed eco-friendly components, grinding and/or sprucing up, discharge machining sintering. Milling machining isn't feasible as a result of quickly and unforeseen milling application problems. In order to allow ceramics as well as tungsten carbides milling new tool systems are actually designed. The systems include Nano scaled tungsten carbide tough metals, revolutionary covering methods, brand new milling application models too as taken milling tasks. By merging the systems it becomes doable to mill various levels of tough metals as well as ceramics with hardness values more than 1200HV10 [2].

The paper dealt with hardened steel's machining with carbide end mills. The research comprises of comparison of various milling tools on their durability in hardened steel's machining. For the various geometry of cutting tool, tool material's substrate or thin-film deposition were utilized. This study primarily focuses on broad comparison on every cutting tool. DIN X210Cr12 was utilized for test work material. Generally, materials were used for tools for cold forming, grinding tools or production of highly stressed molds. Experiment's initial part detects the cutting conditions that with A. S. Kondratov might be short-term test. Also, in experiment's second part utilization of cutting conditions is done that is each tool's long-term test. In hardened steel's side milling, each tool's sturdiness and flank wear is assessed. These materials are used in engineering industry, such as in dies and molds, forming tools or cutting tools production. For these material's competitive and productive machining, machining standard must be increased and machining costs be reduced constantly. Here, 4different milling tools are compared in DIN X210Cr12 hardened steel machining with their durability. Good results are greatly influenced by the coating and related processes. Carbide substrate and thin-film's honest coherence with no defect is provided by carbide substrate's suitable choice and leading edge (micro-geometry) suitable preparation. These results can be utilized for hard machining cutting tools' further research and development [6].

Searching on optimization of cutting parameters was carried out for boost the cemented carbide application lifetime in hardened metal's high speed milling. Tool components microstructure image evaluation was carried out figure out the representative component dimensions as well as typical grain diameter. The original tool components microstructure state was assessed depending on micromechanics as well as harm technicians. Limited component simulation of the milling procedure was carried out acquiring the tool worry. The initial harm of the device as well as simulated tool pressure had been built-in depending on the idea of harm equivalent anxiety. Evolution and distribution of the harm equivalent pressure on the tool frame was analysed and an innovative signal was brought forward for slicing parameter optimization. On the new signal foundation, a slicing parameter optimization technique was suggested. Experimental tests proved that the suggested optimization technique could be utilized to determine the most effective slicing parameter mixture and extend the cemented carbide application lifetime in high speed milling procedure [7].

Exceptional mechanical and physical properties like low thermal conductivity, low friction factor, as high surface hardness and stable chemical properties are possessed by coated carbide tools. Additionally, in comparison to CBN and ceramic tools, better economic applicability is there in coated carbide tools as well as for hard machining they were used globally. There are several researchers that investigated the coated carbide tool's cutting performance in hard machining [8].

In hardened steel's high speed milling, with increasing cutting speed there is decrease in surface roughness. In high speed machining, surface roughness is affected by the feed per tooth. With feed per tooth increasing, surface roughness also increases. When larger diameter tool is used better surface roughness is attained [9].

A study was commenced for investigating P10TiN coated carbide performance which is inserted at high cutting speed regime in hardened AISI H13 tool steel (50±3 HRC) finishing and semi-finishing end milling. Also, cut depth, cutting speed, and feed rate effects were examined by experiments. For milling conditions' tested range, results showed that cut depth and feed rate greatly affects the tool life. Though, cutting speed doesn't considerably affect tool life against previous researcher's findings [10].

3. Experimental Procedure

The milling experiments are implemented under wet cutting conditions on a CNC Milling machine. This experimental study aims in analyzing the importance as well as effect of the tool material, different suitable coatings on HDS H-13 material and also cutting parameters' effects under wet cutting conditions in end milling machining on the surface roughness tool-chip interface temperature. For this investigation, Taguchi's method is utilized as a DOE. Optimal machining parameters are determined by using Taguchi method in of HDS H-13 milling under wet milling conditions with Bi-layer coated tungsten carbide tool. Also, ANOVA is used to evaluate the experimental results.

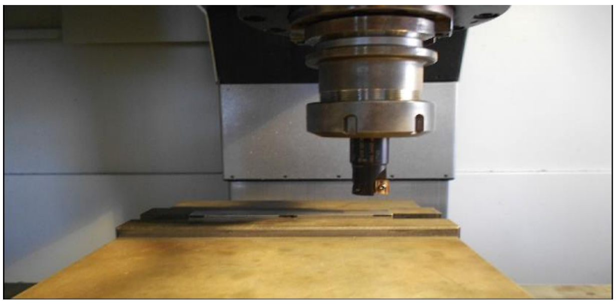

Fig -1. CNC Milling setup

Process Parameter	Level		
	Low (-1)	Medium (0)	High (+1)
Cutting Speed (m/min)	9000	11000	13000
Feed(mm/min)	450	600	850
Depth of cut (mm)	0.05	0.15	0.25

Chart -1. Shows Parameters and their level with coded value and actual value (3 levels each for 3 factor)

4. Design of Experiment

Run	Speed S (rpm)	Feed F (mm/min)	Depth of cut Doc (mm)
1	9000	450	0.05
2	9000	600	0.15
3	9000	850	0.25
4	11000	450	0.15
5	11000	600	0.25
6	11000	850	0.05
7	13000	450	0.25
8	13000	600	0.05
9	13000	850	0.15

Chart -2. Design of experiment

In CNC Milling machine ARTCAM Software is used which is SEIMENS Control. Firstly, using Art-cam software Program designed for each run in Roughing as well as finishing operation. Following are some steps in Art-cam software for designing the Program.

5. Results and Discussion

Experimental Results:
In this chapter, the experimental results were obtained by conducting experiments based on DOE by RSMs' Central composite design using Minitab 18 software and then the results obtained are analyzed and are discussed in the following order:

1) Surface Roughness (Ra)
2) Average Chip-Tool Interface Temperature (θi)

Readings were taken for three different tools of different coatings. First for uncoated tool, then for Mono-layer coated tool and last for Bi-layer coated tool.

Run	S	F	D	Ra	Temperature

	rpm	mm/min	mm	Micron	θ_i Degrees
1	9000	450	0.05	0.325	90
2	9000	600	0.15	0.354	92
3	9000	850	0.25	0.360	93
4	11000	450	0.15	0.310	91
5	11000	600	0.25	0.322	93
6	11000	850	0.05	0.258	92
7	13000	450	0.25	0.290	94
8	13000	600	0.05	0.220	95
9	13000	850	0.15	0.239	96

Chart.3 Exprimentation for Bi-Layer coated tool

5.1 Effect of Bi-layer coating tool on Surface roughness and Temperature

In this experiment surface roughness is main influence parameter which is measured by Mitutoyo SJ410 Ra value tester. It is observed that Surface roughness in near Bi-layer coating tools Machining is less as compare to mono-layer or uncoated tools as shown in table. Table show when feed rate increases surface roughness also somewhat increases. But when speed increases surface roughness decreases.

5.2 Adequacy and ANOVA for RaF & θi (Surface roughness and Chip –tool interface temperature using Bi-layer coated tool)

Adequacy of the Model for RaFF & θiF:

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution	
Speed	2	24.6	24.6667	12.3333	37.00	0.026	77.08%	Most Significant
Feed	2	0.6667	0.6667	0.3333	1.00	0.080	2.08%	Not Significant
DoC	2	6.0	6.0	3.0	9.00	0.040	18.75%	Least Significant
Error	2	0.6667	0.6667	0.3333			2.08%	
Total	8	32.0					100.00%	

Chart -4. Analysis of Variance

S	R-sq	R-sq(adj)	R-sq(pred)
0.577350	97.92%	91.67%	87.81%

Chart -5. Model Summary

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	83.000	0.192	(82.172, 83.828)	431.28	0.000	
Speed						
9000	-1.000	0.272	(-2.171, 0.171)	-3.67	0.067	1.33
11000	-1.333	0.272	(-2.504, -0.162)	-4.90	0.039	1.33
Feed						
450	0.333	0.272	(-0.838, 1.504)	1.22	0.345	1.33
600	-0.333	0.272	(-1.504, 0.838)	-1.22	0.345	1.33
DoC						
0.05	-1.000	0.272	(-2.171, 0.171)	-3.67	0.067	1.33
0.15	0.000	0.272	(-1.171, 1.171)	0.00	1.000	1.33

Chart -6. Coefficients

Regression Equation:

Temp = 83.000 - 1.000 Speed_9000 -
1.333 Speed_11000 + 2.333 Speed_13000
+ 0.333 Feed_450
- 0.333 Feed_600 - 0.000 Feed_850 -
1.000 DoC_0.05 + 0.000 DoC_0.15
+ 1.000 DoC_0.25

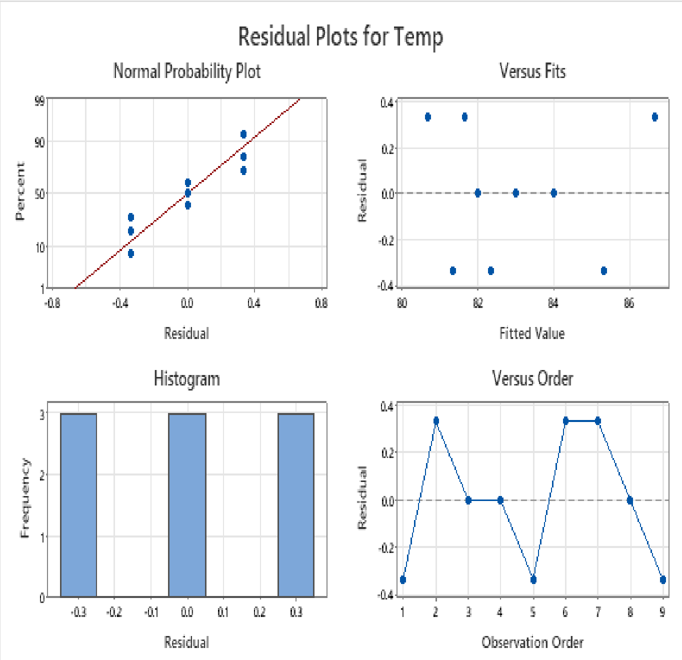

Chart -7. Residual Plot for Surface Roughness (R_{aF})Avg Chip-tool interface Temperature (θ_{if}) using Bi-layer coated tool.

The final step of Dissertation is the confirmation experiment. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. After determining the optimum levels, a new experiment is designed and conducted with optimum levels of the machining parameters for both Mono-layer coated and Bi-layer coated conditions. The optimized values of cutting velocity obtained under Mono-layer coated and Bi-layer coated are 137.2373 m/min and 89.2353 m/min, as these values cannot be set on the machine so the nearer values which are set on the machine are 143.256m/min for Mono-layer 92.519 m/min for Bi-layer coating, similarly the optimized value of feed rate set under Mono-layer is 0.108 mm/rev instead of 1.070 mm/rev. The percentage variation between predicted values and confirmation experimental values for the responses is then calculated.

After performing confirmation experiment it was observed that the percentage variation between predicted values and confirmation experimental values for the responses under Mono-layer coated and Bi-layer condition is found to be less than 3%.

6. CONCLUSIONS

The developed experimental investigation of the milling process makes it possible to study the effects ofprocess parameters such as the speed, feed, and depth of cut.The results of the presented investigations show the benefits of using Bi-layer coating for the material HDS-H13 in comparison with mono layer and uncoated tool, Result 30% and 35% reduction in Ra and Rz surface roughness respectively. Using Bi-layer coating tool life increases. Performance changes as we use coating layers of different material.

It may be possible to improve all selected parameter. Itis a great convenience for engineers to focus on both accuracy of products and service life of tool thus improving production efficiency. Overall, all the machining process has some merits and demerits, but in competitive world optimum solution required for increasing the productivity.

5.2 FUTURE SCOPE

With increasing demand for a high-quality product with the lesser price, the manufacturing industry has been competitive. Machining is the fundamental process of any manufacturing process and companies are always in seek of better technology the scope of study in the performance of machining process is high. Some of the fields of study for future work can be listed as:

- Research on the different coatings of the cutting tool can be furthered because of its cheapness and ease of technology.
- Further research can be extended to study the performance of end mill cutting tool with a variety of metal coating. Since the surface finish is a crucial factor for any product manufactured the way to increase surface finish may be a great field of study.
- The study can be continued on the life of the cutting tool and its wear mechanism.
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5.3 APPLICATION

- Bi-layer coating tool has greater enhancements in productivity, increases the quality of the machined parts and minimizes the production cost.
- It is used in every machining process
- By using this tool life will be increases.
- By using this Bi-layer coated tooling surface roughness reduces 30% to 35%.

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