Influence of Carbon Coatings on Tungsten Carbide Tool Inserts

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Abstract – The most popular and often used high production tool materials nowadays are tungsten carbides. The acceleration of enhanced cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance is the productivity increase of manufacturing processes. This led to the creation of hard coatings for cutting instruments, which are thin films with one to hundreds of layers. By reducing the rate at which cutting tools wear out, these hard coatings have been shown to up the tool life by a factor of up to 10. As a result of the longer tool life, tool changes can be made less frequently, allowing for larger batch sizes to be produced, which lowers setup costs and setup time in addition to manufacturing costs.Tools made of coated tungsten carbide (WC) are the best to use when machining tough, challenging metals in the manufacturing sector. While creating a superior surface finish during machining, these tools provide good resistance to wear and friction. Additionally, these WC machines have a proven track record of productivity in creating lots of parts.In the present work ANOVA software is used to estimate the parameters which influence the tool life and surface roughness.The input parameters were Spindle speed (450, 710, 1800 rpm), Feed rate (0.05, 0.063, 0.1 mm/rev), Depth of cut (0.5, 1.0, 1.5 mm) and the response variables were the Surface roughness and tool wear and the effect of Speed, Feed and Depth of Cut on surface finish of Work Piece is studied for the machined surface.

Keywords –Depth of Cut, Speed, Feed, Surface Roughness, EN-24, Stainless Steel and Tungsten Carbide.

1. INTRODUCTION

Hard coatings that are applied to cutting tools provide better and more reliable surface roughness of the machined work piece in addition to extending tool life. Chemical vapour deposition (CVD) or physical vapour deposition (PVD) hard coatings are used on the majority of carbide cutting tools now in use. These coatings' high hardness, wear resistance, and chemical stability have been shown to improve tool life and machining efficiency. Traditionally, coatings were produced using the CVD process, which uses a variety of chemical reactions to deposit thin films on cutting tools.

The high underlying qualities of an allotrope of carbon known as diamond have attracted a lot of positive attention from researchers, machinists, workers, etc. in the fields of science and engineering. As we already know, the hardest and least compressible substance is a diamond. At room temperature, it has one of the best thermal conductivities. On a substrate material like tungsten carbide, the diamond film is grown using the thermal chemical vapour deposition (CVD) technique (WC). Because of the potential applications for this technique in the fields of technology and manufacturing, many researchers and scientists have been paying close attention to it for a long time.

A steel alloy called EN24 with a 1.5% nickel, 1% chromium, and 0.2% molybdenum content has been around for more than a century. The tensile strength of EN24 can be heat treated to a variety of values, ranging from 850–1000 N/mm2 ('T' condition) to 1550 N/mm2 ('Z' condition). High tensile strength EN24 that has been heat treated also has good ductility and shock resistance. Good impact values can be produced at low temperatures. EN24 was utilised to make a variety of parts and components for these industries when it first started to become more popular in the early 1900s. It was categorised as a wrought steel for autos and aviation at the time. It is most frequently used as EN24T, and thanks to its excellent high tensile qualities in T state, the manufacturing industry uses it extensively.

Inserts are removable cutting tips, which means they are not brazed or welded to the tool body. They are usually indexable, meaning that they can be exchanged, and often also rotated or flipped, without disturbing the overall geometry of the tool. This saves time in manufacturing by allowing fresh cutting edges to be presented periodically without the need for tool grinding, setup changes.

Cutting tools play a very important role in the manufacturing industry as they would determine the quality of a finished product. The performance of a cutting tool directly affects a machines' productivity if they are attached to a cutting machine. Manufacturers take into consideration several factors that concern the effectiveness of cutting tools before purchasing cutting tools for their machining systems. Some of these factors can be that the tool has to have the ability to withstand rigorous operating conditions, perform at very high speeds, resist wear and tear, and it should not deform while in operation. As demands for better cutting tools increase, manufacturers of cutting tools continuously reinvent and develop their products to surpass the expectations of their customers.

Surface roughness most commonly refers to the variations in the height of the surface relative to a reference plane. It is measured either along with a single line profile or along with a set of parallel line profiles (surface maps). It is usually characterized by one of the two statistical height descriptors advocated by the American National Standards Institute (ANSI) and the International Standardization Organization (ISO). These are (1) Ra, CLA (center-line average), or AA (arithmetic average) and (2) the standard deviation or variance (σ), Rq, or root mean square (RMS). Two other statistical height descriptors are skewness (Sk) and kurtosis (K); these are rarely used. Another measure of surface roughness is an extreme-value height descriptor Rt (or Ry, Rmax, or maximum peak-to-valley height or simply P–V distance). Four other extreme-value height descriptors in limited use, are Rp (maximum peak height, maximum peak-to-mean height or simply P–M distance), Rv(maximum valley depth or mean-to-lowest valley height), Rz (average peak-to-valley height), and Rpm (average peak-to-mean height).

There are two methods used for measuring surface roughness. 1. Surface inspection by comparison method e.g., tough inspection, visual inspection, scratch inspection, microscopic inspection, visual inspection, surface photography, reflected light intensity, etc. 2. Direct instrument method e.g., light section method, Forster surface roughness tester, Profilograph, Tomlinson surface roughness meter, Telysurf, etc.

Aluminium is used as a matrix material because of its attractive characteristics and second most available material.

2. LITERATURE SURVEY

In the finish hard turning of AISI H13 steel, Tugrul O Zel et al. [1] presented the effects of cutting edge preparation geometry, workpiece surface hardness, and cutting circumstances on the surface roughness and cutting forces. They discovered that in addition to the cutting circumstances, the geometry of the cutting edge and the hardness of the workpiece's surface also have an impact on the cutting forces. Decreased tangential and radial forces were produced as a result of the workpiece's lower surface hardness and tiny edge radius.

Hard coatings have been shown to enhance the performance of cutting tools in demanding machining operations like high-speed machining, according to research by Jeong Suk Kim et al.[2] Additionally, under various high spindle speeds, the link between the machining properties and the Si contents was examined. It has been demonstrated that the Si concentration increased tool life by up to 50%.

The findings of experimental work in dry turning of austenitic stainless steels (AISI 304 and AISI 316) utilising CVD multilayer coated cemented carbide tools were presented by Ibrahim Ciftci [3]. TiC/TiCN/TiN and TiCN/TiC/Al2O3 coated cementide carbides were employed as the cutting tools. They discovered that the values of the machined surface roughness are considerably influenced by the cutting speed. The surface roughness values dropped as cutting speed increased until a minimal value was achieved, after which they began to grow.

When continuously turning AISI 8620 steel, Renato Franc oso de A vila et al. [4] examined the effectiveness of uncoated and coated carbide tools (ISO grade K10) with a 3 m thick monolayer of TiN (manufactured by PAPVD). Their findings show that while utilising coated cutting tools for machining, there are two separate crater wear rates present, whereas an uncoated insert showed a larger and single wear rate.

The tool life and wear behaviour at various machining parameters was studied by C.H. Che Haron et al [5]. The wear progression for both types of carbide tools experienced three stages of wear rate, including initial, gradual, and abrupt stages of wear mechanism. Coated carbide (KC 9125) and uncoated carbide (K 313) were utilised in turning tool steel AISI D2 bar with a hardness of 25 HRC. Low feed rate of 0.05 mm/rev resulted in slow wear rate and consistent flank wear. In general, coated tools outperformed uncoated tools in performance. The use of coated tools produced a superior surface quality and increased tool life.

When dry turning the aluminum-silicon hypereutectic alloy A390, Prabhu U. Arumugam et al. [6] compared the performance of polished chemical vapour deposited (CVD) diamond tool coated carbide tool inserts to that of unpolished CVD diamond coated carbide tool inserts. They showed that, in contrast to traditional diamond tools (PCD and unpolished CVD), CVD diamond-coated polished tools generate less particles, improve tool life, and lessen cutting pressures.

3. EXPERIMENTAL SET UPS & METHODS

Automated all geared head lathe: In the Mechanical Engineering field Lathe machine plays an important role in Manufacturing. The machine tool that is used to remove unwanted metals from the workpiece to give the desired shape and size is called a "Lathe machine". Lathe machine is also known as"Centre Lathe" because of two centers between which the job can be held and rotated. Lathe machine is one of the most important machine tools which is used in the metalworking industry. It operates on the principle of a rotating workpiece and a fixed cutting tool. The cutting tool is feed into the workpiece which rotates about its axis causing the workpiece to form the desired shape. He is also known as the father of the entire tool family. It was invented by DAVID WILKINSON (05 Jan. 1771 – 03 Feb. 1852) function of the Lathe machine is to remove excess material in the form of chips by rotating the workpiece against a stationary cutting tool.

Figure 1: Automated all geared head lathe.

Tool Insert: The tool insert used isTungsten Carbide and Carbon Coated Tungsten Carbide CCMT 09T304 having the specification of C (Insert shape): Rhombic 800, C (Relief angle): 70, M: Tolerance class, T (Chip breaker and clamping system): Rounded, 09 (Cutting edge): 0.9mm, T3 (Insert thickness): 3.97mm and 04 (Nose radius): 0.4mm.

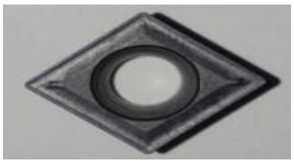

Figure 2: Tool Insert Used.

Material: A steel alloy called EN24 with a 1.5% nickel, 1% chromium, and 0.2% molybdenum content has been around for more than a century. The tensile strength of EN24 can be heat treated to a variety of values, ranging from 850–1000 N/mm2 ('T' condition) to 1550 N/mm2 ('Z' condition). High tensile strength EN24 that has been heat treated also has good ductility and shock resistance. Good impact values can be produced at low temperatures.

MINITAB 19: Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was published in 1986, and there has been no significant development since then.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania. Minitab Inc. also produces Quality Trainer and Quality Companion, which can be used in conjunction with Minitab: the first being and Learning package that teaches statistical tools and concepts in the context of quality improvement, while the second is a tool for managing Six Sigma and Lean Manufacturing.

Minitab is a computer program designed to perform basic and advanced statistical functions. It combines the user-friendliness of Microsoft Excel with the ability to perform complex statistical analyses. The Figure shows the MINITAB worksheet with the Taguchi design selected for the design. MINITAB was the most popular statistics package in use in the social sciences. It was first used in teaching and research although some users regarded it as a more limited research tool. No one found MINITAB difficult to use.

Surfcom FLEX 50-A: Surfcom FLEX 50-A is a compact, hand-held surface tester; there is no easier way of measuring, evaluating, and documenting surface roughness. Surfcom flex 50-A measures not only flat, horizontal but also vertical, overhead surfaces and simple measurement to waviness. In addition, 30 complete data records can be stored in the built-in memory and recalled at any time additionally USB memory can be connected in Surfcom FLEX to save more data and a Mini USB connector is equipped with Surfcom FLEX and able to connect with PC. The data can be sent to PC and various analysis is available with ACCTee software. It can measure roughness average (Ra), an average maximum height of the profile (Rz), and maximum roughness depth (Rmax), etc., Table 5.6 gives the technical specification of Surfcom FLEX 50-A meter. It is easy to carry by compact design, it can be used anywhere, it has a built-in printer so we can take the print out directly just by inserting the print paper.

Figure 3: Surfcom FLEX 50-Aused for Measuring surface roughness.

Profile projector: An optical comparator (often called just a comparator in context) or profile projector is a device that applies the principles of optics to the inspection of manufactured parts. In a comparator, the magnified profile of a part is projected upon the screen, and the dimensions and geometry of the part are measured against prescribed limits. It is a useful item in a small parts machine shop or production line for the quality control inspection team.

The projector magnifies the profile of the specimen and displays this on the built-in projection screen. On this screen, there is typically a grid that can be rotated 360 degrees so the X-Y axis of the screen can be aligned with a straight edge of the machined part to examine or measure. This projection screen displays the profile of the specimen and is magnified for better ease of calculating linear measurements. An edge of the specimen to examine may be lined up with the grid on the screen. From there, simple measurements may be taken for distances to other points. This is being done on a magnified profile of the specimen. It can be simpler as well as reduce errors by measuring on the magnified projection screen of a profile projector.

Figure 4: Profile projector

Methodology Followed:

- Constructing the Taguchi Table according to L9 Orthogonal Array.
- Conducting the experiments by using the Taguchi Table in the Automated All Geared Head Lathe for the Turning Operation.
- After machining the En-24 work material, its surface roughness is measured using the Surfcom Flex.
- Tool wear is measured by using a metallurgical microscope.
- Optimization of cutting parameters to get a high surface finish by using the Taguchi technique and ANOVA.
- Comparison between Carbon coated and uncoated Tungsten Carbide tool inserts.

4. RESULTS & DISCUSSIONS

The optimizations of process parameters are usually performed as per the traditional Taguchi approach using a signal-to-noise ratio. A higher signal-to-noise ratio means closer to optimal process parameters. It can optimize the response and able to optimize the number of responses. The experimental design matrix based on the Taguchi L9 orthogonal array technique and corresponding values of responses is shown in Table 1 shown below. Two main machinability indicators that are surface roughness and tool wear have been considered as the major responses in the present work.

Parameters	**Level 1**	**Level 2**	**Level 3**
Spindle speed (rpm)	450	710	1800
Feed rate (mm/rev.)	0.05	0.063	0.1
Depth of cut (mm)	0.5	1.0	1.5

Taguchi Analysis: Table 2 below shows theSurface roughness in Microns on turning En-24 Steel using Tungsten CarbideCCMT 09T304tool inserts:

Level	Spindle Speed	Feed Rate	Depth of Cut
1	3.2846	2.9614	1.2876
2	2.9688	3.6846	2.0264
3	-2.6756	-2.1874	-0.4086
Delta	6.0124	4.9876	2.9862
Rank	1	2	3

The most important criteria for surface roughness on machining En-24, according to Taguchi study, are Spindle Speed is the most important factor when utilising an uncoated Tungsten Carbide tool insert, followed by Feed Rate, and DOC is the least important component, as shown in above Table. It can be perceived that the depth of surface unevenness increased as the Speed rate rose. With a high Speed rate, significant Speed markings are maintained, as well as a conspicuous built-up edge, resulting in degraded surface quality with finish. Surface roughness is observed to diminish as cutting Feed is increased. As the build-up edge diminishes, a high cutting speed favours surface eminence. In other words, the surface polish improves as a result of less build-up edge development by high cutting Feed rates. Chip breakage occurred very quickly at low cutting speeds, resulting in deterioration of surface quality.

Table 3 shows the Signal to Noise Ration for Carbon Coated Tungsten Carbide Tool Inserts for Surface Roughness.

Level	Spindle Speed	Feed Rate	Depth of Cut
1	4.1596	5.236	5.6486
2	3.9662	4.2962	4.8916
3	4.6128	4.689	4.1284
Delta	1.9686	1.496	2.6815
Rank	2	3	1

When turning with Carbon coated Tungsten Carbide tools, the surface superiority of the machined surface decayed more quickly in the uncoated tool equated to a coated tool with little coarseness. The existence of carbon coating, which results in a low coefficient of friction amongst the tool chip contact, could be the cause. Finally, it may be concluded that carbon coated tools have improved the surface finish. The surface unevenness profiles of uncoated plus carbon coated tools were examined at the same machining variable, as shown in Tables 2 and 3. Surfaces machined with uncoated tools exhibit more imperfections than surfaces produced using carbon coated tool inserts.

Signal to Noise Ratio for uncoated Tungsten Carbide tool inserts: For uncoated tungsten Carbide tool inserts, the most predominant factor of tool wear is Feed Rate followed by Speed and DOC as shown in Table 4. While for Carbon coated tool inserts most predominant factor of tool wear is also Feed Rate afterwards DOC then Speed as shown in Table 5.

Table 4. Signal to Noise Ration for Uncoated Tungsten Carbide Tool Inserts for Tool Wear

Level	Spindle Speed	Feed Rate	Depth of Cut
1	-16.86	-24.92	-12.86
2	-14.22	-19.84	-21.22
3	-26.86	-22.32	-24.74
Delta	13.12	15.66	12.44
Rank	2	1	3

Table 5. Signal to Noise Ratio for Carbon Coated Tungsten Carbide Tool Inserts for Tool Wear

Level	Spindle Speed	Feed Rate	Depth of Cut
1	-13.86	-16.84	-12.44
2	-11.42	-19.48	-8.22
3	-28.46	-22.88	-14.66
Delta	10.96	12.44	11.44
Rank	3	1	2

Cutting speed, feed, and DOC were found towards increased tool wear in both Carbon coated plus uncoated Tungsten Carbide tool Inserts when they were increased. Because of the high friction on the chip-tool boundary, tool wear increases thru cutting Feed Rate in the case of the uncoated Tungsten Carbide tool inserts. The chip travels the flank face at high speed as the Feed increases, resulting in a non-uniform surface roughness on the uncoated tool's surface. As a result, the chip movement on an uncoated tool produces a high coefficient of friction, resulting in a greater temperature than on a smooth surface (owing towards low coefficient of friction on coated tool). The greater temperature at the chip-tool boundary aided work material plastic distortion, and tougher particles such as nitrides and oxides degraded some tool material.

Surface roughness versus spindle speed, feed rate, DOC:

The best machining parameters aimed at surface roughness for tungsten carbide tool inserts were observed, are speed=1800 rpm, feed rate=0.1 mm/rev, and DOC=1.5 mm. For Carbon Coated Tungsten Carbide Tool inserts the ideal machining parameters. 710 rpm, 0.063 mm/rev feed rate, then 1mm DOC.

Tool wear versus spindle speed, feed rate, DOC:

The best machining parameters the tool wearfor tungsten carbide tool inserts were observed, are speed=710 rpm, feed rate=0.063 mm/rev, and DOC=0.5 mm. For Carbon Coated Tungsten Carbide Tool inserts the ideal machining parameters. 1800 rpm, 0.063 mm/rev feed rate, then 1mm DOC.

CONCLUSIONS

i. The present study is concerned with the turning of Stainless Steel En-24 by using the Taguchi technique and ANOVA to optimize the surface roughness and tool wear. The machine used to conduct the experiment was an Automated all geared head lathe. The experiments were performed based on L9 Orthogonal Arrays.

ii. The input parameters were Spindle speed (450, 710, 1800 rpm), Feed rate (0.05, 0.063, 0.1 mm/rev), Depth of cut (0.5, 1.0, 1.5 mm) and the response variables were the Surface roughness and tool wear. After the experiments were conducted, the response variables were tabulated and analysis was conducted.
iii. The most affecting parameters among the three cutting parameters i.e., spindle speed, feed rate and depth of cut for the surface roughness, the most significant factor is the depth of cut followed by the spindle speed and the least significant is the feed rate. For the tool wear, the most significant factor is spindle speed, followed by the depth of cut and the least significant is the feed rate.

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