# Effect on surface roughness and cutting force during hard machining of AISI D2 tool steel using AlCrN coated tool using OVAT

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***ABSTRACT:*** *In modern manufacturing, benefits of hard machining process are reduced lead time and environment hazards and improve productivity. D-Grade tool steel materials are largely used in the manufacture of cold forming dies due to excellent wear characteristics and deep hardening. AISI D2 tool steel is used as work material for the current experimentation. Many researchers demonstrated that AlCrN coating, which had been developed recently, gave better wear protection than other coated tools. The present paper gives the details of machining experiments of AISI D2 tool steel using AlCrN coated end mill tool using One-Variable-At-a-Time (OVAT). The aim of the present study is to develop a relationship between cutting force and surface roughness with input parameters (cutting speed, feed, Depth of cut and width of cut). Kistler dynamometer was used to measure cutting force and surf test is used to measure surface roughness.*

***Key Words: :*** *AISI D2 tool steel, AlCrN coated tool, OVAT*

## 1. INTRODUCTION

In global market, manufacturing conditions, satisfaction of customer requirement without compromise quality are becoming anmajor issue to sustain in competitive market. One of the most widely used manufacturing processes is milling process which is interrupted cutting process to remove chip to obtain required shape [1]. In manufacturing industries, milling process is widely used to manufacturing of die, automobile parts and aerospace industries. The cutting circumstances are more adverse than that in turning [2]. Presently, Hard Milling is the best alternative to EDM (Electrical discharge machining) and grinding for hard material which hardness greater than 45 HRC. For high productivity and environment friendly machining process, milling process is despite of its potential compare than other processes like grinding and EDM processes. Milling process for hard material is reduced lead time and machining costs compare than other traditional processes [3]. In die and moulds making industries, machining of hard material is challenging task due to high tool wear, higher tooling and handling cost [4].

In the manufacture of cold forming dies, Grade D Tool steel materials are largely used due to its excellent deep hardening and wear characteristics.V. N. Gaitondeet al, were done experiment on AISI D2 tool steel to evaluate machinability with analysis of cutting temperature, tool wear and surface roughness [5]. For hard machining, tool wear is major issue. To overcome this issue, Coating can effectively improve the tool life.Coating of cutting tool enhance the wear resistance, oxidation resistance, reduce temperature variation in tool and improve lubricity of the tool [6]. During the last two decades, numerous studies have done on different coated tool such as CrN, TiN AlCrN, AlTiN etc. Experiments were carried out on austenitic stainless steel by using hard AlTiN, AlCrN PVD coated tool. The superior oxidation resistance and hot hardness of AlCrN-based coatings as compared to AlTiN ones [7]. Finite element modeling and simulation in dry hard orthogonal cutting AISI D2 tool steel with CBN cutting toolwas investigated by L. Tang et al.Hard machining in dry condition give best results and substantial advantages like decline manufacturing cost, reduce time for finish machining and improve surface quality [8].

Significant flank wear is the major factor for tool performance and tool wear. Some research work has been proved that high tool flank wear in up milling operation compare than down milling operations[1]. Hard milling of AISI H13 steel with optimal cutting parameters was analyzed for significant effect on cutting force and surface roughness by Y. W. Tongchao Ding et al [9]. In this experiment, cutting forces were measured by Kistler tool dynamometer type 9257B which mount on the machine table of milling machine. Experimental investigations were carried out by end milling process on hardened Impax Hi hard tool steel (55 HRC) by Bala Murugan Gopalsamy et al [3]. They concluded that cutting speed 50-180 m/min, width of cut 20 mm, feed 1 mm/tooth and depth of cut 0.5 mm were best parameters for rough machining. Cutting speed 204 m/min, width of cut 0.2mm, feed 0.1-0.2 mm/tooth and depth of cut 0.Cutting speed 204 m/min, width of cut 0.2mm, feed 0.1-0.2 mm/tooth and depth of cut 0.2mm were best parameters for finish machining [10].

Cutting speed 90-150 m/min, width of cut 8 mm, feed 0.25 mm/tooth and depth of cut 0.5 mm were best parameters for rough machining on DIEVAR tool steel. Cutting speed 204 m/min, width of cut 0.2 mm, feed 0.1-0.2 mm/tooth and depth of cut 0.2 mm were best parameters for finish machining on DIEVAR tool steel [3]. Experimental and theoretical study on heat flow when machining of AISI H13 and AISI D2 tool steel by using ball nose end mills (TiAlN and tipped with PCBN) [11]. Flank wear is main tool wear. Chipping, adhesion and attrition were responsible for flank wear. Due to this, tool life is less than 40m length of cut when end milling of AISI D2 tool steel (58 HRC) [12]. End milling of AISI D2 tool steel is analyzed to develop tool life model by using PVD TiAIN coated carbide end mill tool. M. A. Lajiset al. developed mathematical model which indicate relation between tool life and machining variables by using concept of RSM. It was developed by the linear model (first order) as well as quadratic model (second order) [4].
No any work has been done on AISI D2 tool steel with AlCrN coated end mill tool. At present, hardened AISI D2 tool steel is mostly machined by AlCrN coated carbide. Aim of this paper to develop relationship between output response (Cutting force and surface roughness) and input parameters (Cutting speed, feed, depth of cut and width of cut) when AISI D2 tool steel was machined by AlCrN coated tool.

## 2. EXPERIMENT WORK

As part of current research work, AISI D2 tool steel with a hardness of 62 HRC was hard machined. Chemical composition of the cut material can be found in Table 1.

*Table-1 Chemical composition (average %) of machined AISI D2 tool steel*

| C | Si | Mn | Cr | Mo | V | W |
|---|---|---|---|---|---|---|
| 1.560 | 0.280 | 0.340 | 11.700 | 0.560 | 0.210 | 0,.460 |

The hardness of 59 HRC of the testing samples was achieved by hardening (with oil quenching) at 970°C followed by 2 hours tempering at 710°C. Machining was done on 40x80x16mm AISI D2 tool steel (59HRC). Cutting experiments were carried out by Jyoti CNC machining Centre PX10. Walter made AlCrN coated flat end mill tool (MC232-10.0W4B-WJ30ED) with 10 mm diameter was used for experimental work as shown in fig-1.

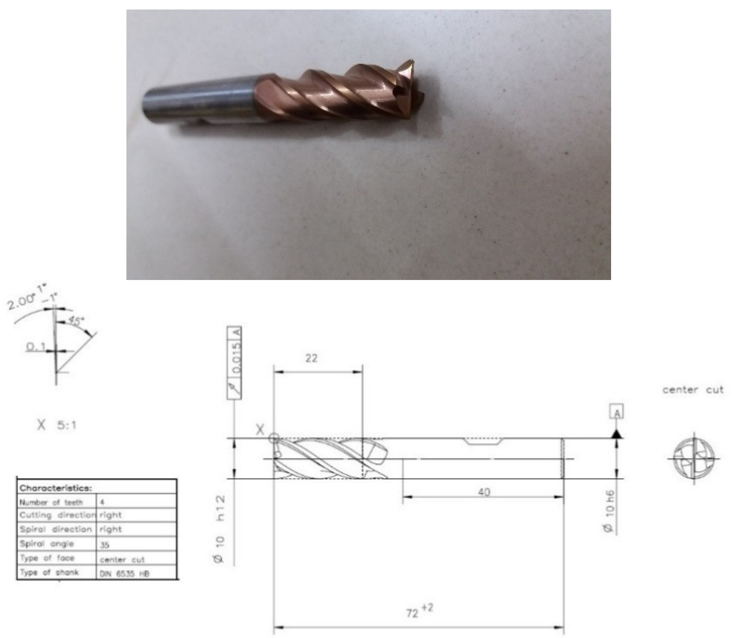
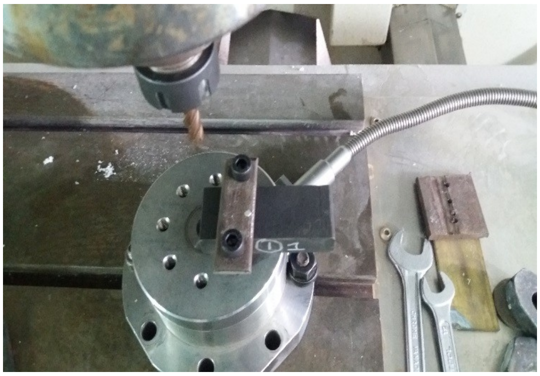



*Figure-1 AlCrN coated tool*

A tool dynamometer (9272, Kistler made) was mounted on the table of the machine tool to measure the cutting force signals during machining as shown in fig-2. The signals were amplified through a charge amplifier and analog signals were converted using A/D acquisition card (PCI-6-23E, NI) and stored in a computer. LabVIEW was employed for cutting force data acquisition. By using Dynamometer 9272, Four-component dynamometer for measuring a torque Mz and the three orthogonal components of a force were measured during machining operation.

For experiment work, OVAT tests were performed for an axial depth of cut ($a_p$) from 0.1 to 1.5 mm, width of cut (ae) from 1.5 to 10 mm, feed (fz) at 127-1500 mm/min and for cutting speeds (Vc) from 25 to 250 m/min for PVD coated AlCrN coated end mill tool to achieve relationship between above four parameters with surface roughness and cutting force.



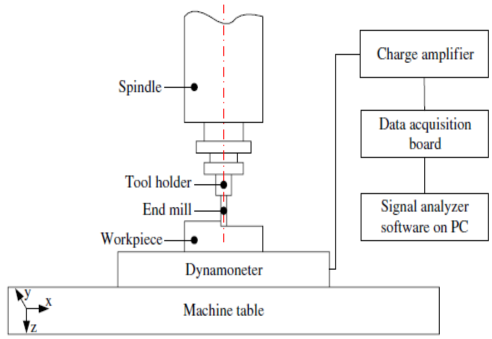



*Figure-2 Experimental setup*

After milling experiments, the measurements of arithmetical mean roughness (Ra) were made on Mitutoyo make surf test SJ-410 measurement instrument. From Table 2-5, Experimental tables were shown where variable one input parameters at a time with fixed all other three parameters.

*Table-2 Experimental reading with Variable WOC*

| SR. NO. | WOC (mm) | Cutting Speed (m/min) | Feed (mm/min) | DOC (mm) | Cutting Force (N) | | | TORQUE | S.R. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fx | Fy | Fz | | |
| 1 | 1.5 | 50 | 509 | 0.5 | 21.784 | 21.972 | 22.259 | 4.160 | 0.673 |
| 2 | 2 | 50 | 509 | 0.5 | 21.784 | 37.231 | 129.080 | 4.160 | 0.431 |
| 3 | 3 | 50 | 509 | 0.5 | 21.784 | 21.972 | 113.826 | 1.109 | 0.708 |
| 4 | 4 | 50 | 509 | 0.5 | 37.048 | 6.713 | 174.871 | 1.109 | 0.839 |
| 5 | 4.5 | 50 | 509 | 0.5 | 6.519 | 21.972 | 205.394 | 1.109 | 0.752 |
| 6 | 5 | 50 | 509 | 0.5 | 21.784 | 6.713 | 266.439 | 4.160 | 0.790 |
| 7 | 6 | 50 | 509 | 0.5 | 6.519 | 37.231 | 312.223 | 4.161 | 0.790 |
| 8 | 10 | 50 | 509 | 0.5 | 52.313 | 6.713 | 754.800 | 4.160 | 1.311 |

*Table-3 Experimental reading with Variable Cutting Speed*

| SR. NO. | Cutting Speed (m/min) | Feed (mm/min) | DOC (mm) | WOC (mm) | Cutting Force (N) | | | TORQUE | S.R. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fx | Fy | Fz | | |
| 9 | 25 | 509 | 0.5 | 10 | 21.784 | 6.713 | 739.538 | 7.212 | 1.300 |
| 10 | 50 | 509 | 0.5 | 10 | 52.313 | 6.713 | 754.800 | 4.160 | 1.311 |
| 11 | 75 | 509 | 0.5 | 10 | 21.784 | 6.713 | 693.755 | 4.161 | 0.783 |
| 12 | 100 | 509 | 0.5 | 10 | 21.784 | 6.713 | 495.358 | 4.161 | 0.791 |
| 13 | 125 | 509 | 0.5 | 10 | 37.048 | 21.972 | 296.962 | 4.161 | 0.555 |
| 14 | 150 | 509 | 0.5 | 10 | 37.048 | 37.231 | 342.745 | 4.160 | 0.344 |
| 15 | 188 | 509 | 0.5 | 10 | 21.784 | 6.713 | 403.791 | 4.161 | 0.303 |
| 16 | 200 | 509 | 0.5 | 10 | 6.519 | 21.972 | 632.710 | 4.161 | 0.244 |
| 17 | 225 | 509 | 0.5 | 10 | 21.784 | 37.231 | 586.926 | 25.523 | 0.243 |
| 18 | 250 | 509 | 0.5 | 10 | 21.783 | 21.972 | 475.520 | 4.109 | 0.398 |

*Table-4 Experimental reading with Variable DOC*

| Sr. No. | DOC (mm) | Cutting Speed (m/min) | Feed (mm/min) | WOC (mm) | Cutting Force (N) | | | TORQUE | S.R. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fx | Fy | Fz | | |
| 19 | 0.1 | 50 | 509 | 10 | 21.784 | 6.713 | 83.304 | 4.161 | 0.811 |
| 20 | 0.3 | 50 | 509 | 10 | 21.784 | 6.713 | 251.178 | 7.212 | 1.612 |
| 21 | 0.5 | 50 | 509 | 10 | 52.313 | 6.713 | 754.800 | 4.160 | 1.311 |
| 22 | 0.8 | 50 | 509 | 10 | 6.519 | 21.972 | 983.719 | 13.316 | 1.741 |
| 23 | 1 | 50 | 509 | 10 | 21.784 | 21.972 | 1151.593 | 10.264 | 1.615 |
| 24 | 1.3 | 50 | 509 | 10 | 21.784 | 21.972 | 1426.296 | 16.367 | 2.219 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 1.5 | 50 | 509 | 10 | 49.194 | 49.224 | 1380.512 | 29.609 | 1.608 |

*Table-5 Experimental reading with Variable Feed*

| Sr. No. | Feed (mm/min) | CuttingSpeed (m/min) | DOC (mm) | WOC (mm) | Cutting Force (N) | | | TORQUE | S.R. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fx | Fy | Fz | | |
| 26 | 127 | 50 | 0.5 | 10 | 21.784 | 37.231 | 266.439 | 7.212 | 0.327 |
| 27 | 382 | 50 | 0.5 | 10 | 21.784 | 21.972 | 388.529 | 1.109 | 0.907 |
| 28 | 509 | 50 | 0.5 | 10 | 52.313 | 6.713 | 754.800 | 4.160 | 1.311 |
| 29 | 637 | 50 | 0.5 | 10 | 21.784 | 6.713 | 724.277 | 1.109 | 1.086 |
| 30 | 800 | 50 | 0.5 | 10 | 21.784 | 21.972 | 1258.422 | 10.264 | 1.302 |
| 31 | 1000 | 50 | 0.5 | 10 | 21.784 | 6.713 | 678.494 | 7.212 | 1.474 |
| 32 | 1200 | 50 | 0.5 | 10 | 6.519 | 21.972 | 1060.025 | 7.212 | 1.460 |
| 33 | 1500 | 50 | 0.5 | 10 | 6.519 | 6.713 | 1655.215 | 7.212 | 1.601 |

## 3. RESULT AND DISCUSSION

### 3.1 Effects of cutting parameters on surface roughness

Figures 3 a-d show the relations between surface roughness and various input parameters (cutting speed, feed, radial depth of cut and axial depth of cut respectively).

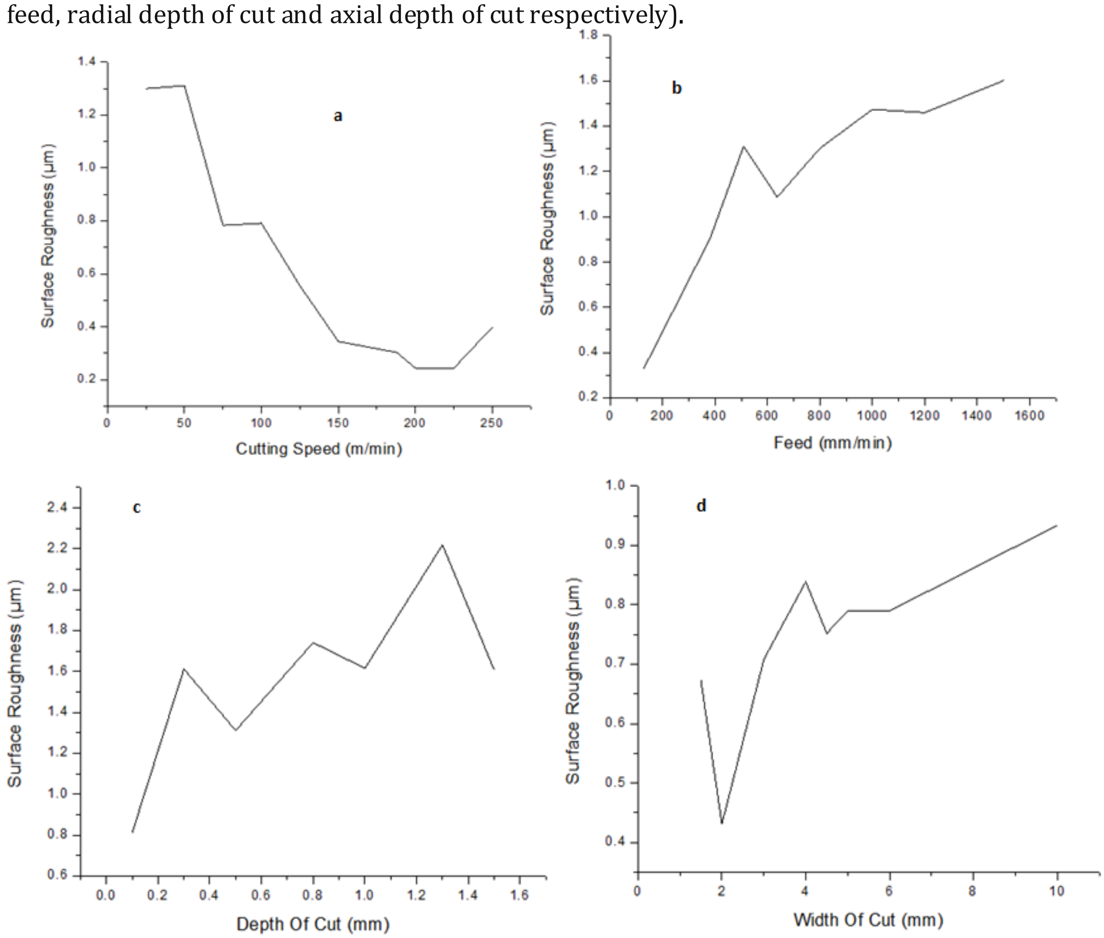



*Figure-3 Relationship between surface roughness Vs a) Cutting Speed b) feed c) Depth of cut d) Width of cut*

When cutting speed ranges from 100 to 120 m/min the surface roughness increases with the increase of cutting speed; while when cutting speed ranges from 120 to 140 m/min, the surface roughness reduces with increasing the cutting speed. When the cutting speed increases from 140 to 160 m/min, the surface roughness has an increasing trend.

Surface roughness reduces when axial depth of cut increases from 1 to 2 mm. Then surface roughness increases rapidly as axial depth of cut increased from 2 to 3 mm. In the range of 3 and 4 mm, surface roughness has a reducing trend. Surface roughness increase with increase feed.

### 3.2 Effects of cutting parameters on cutting forces

When cutting speed ranges from 120 to 140 m/min, the forces reduce with increasing the cutting speed, this is due to the thermal softening which changes the shear angle and thus the necessary plastic deformation.

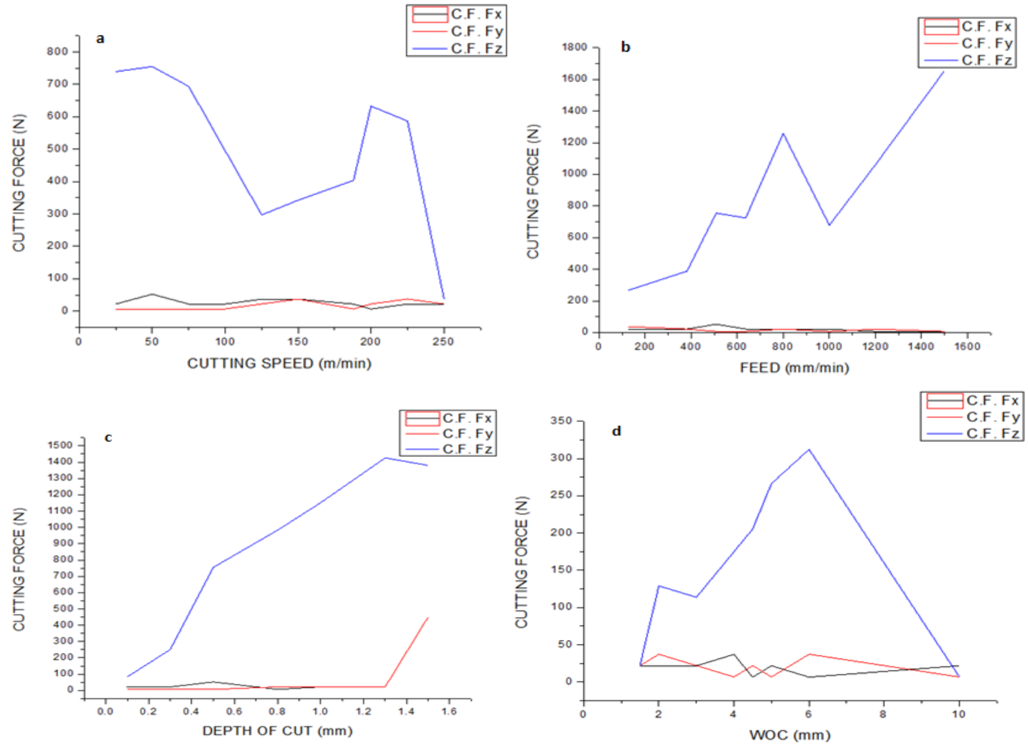



*Figure-4 Relationship between Cutting force Vs a) Cutting Speed b) feed c) Depth of cut d) Width of cut*

When cutting speed ranges from 100 to 120 m/min the cutting force increases with the increase of cutting speed due to an increase in strain and strain rate.

When cutting speed increases from 140 to160 m/min, cutting forces increase rapidly. This might be because that cutting temperature increases with the increase of the cutting speed. When the speed is too high, the cutting temperature may exceed beyond the upper limit working temperature of the coating, and thus the coating would be of no use causing the cutting forces increase rapidly. Cutting forces increase with the increase in feed, radial depth of cut and axial depth of cut due to an increase in chip load.

### 4. CONCLUSION

This paper presents the findings of an experimental investigation of the effect of cutting speed, feed rate, depth of cut and width of cut on the cutting forces and surface roughness in hard milling of AISI D2 (59 HRC) steel with coated carbide tool and the following conclusions are drawn:

1) The minimum cutting forces can be achieved under the following criteria of cutting parameters: Cutting speed v= 125 m/min, fz= 127 mm/min, Width of cut ($a_e$) = 3 mm and Depth of cut ($a_p$) =0.1 - 0.3 mm.
2) The axial depth of cut and the feed are the two dominant cutting parameters that affect the cutting forces.
3) High Surface finish can be achieve with 2 mm width of cut, 150-200 m/min cutting speed, 125-300 mm/min feed and 0.1-0.3 mm Depth of cut, which justifies that the hard milling may replace grinding as a semi-finish process at least.
4) The surface roughness exhibits higher sensitivity to axial depth of cut.

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