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# Evaluation and Selection of Diamond Wheel Grit Size for Solid Carbide End Mill Manufacturing in ANCA CNC Machine

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**Abstract—***The project work was carried out within the company which deals with manufacturing of solid carbide end mill parts. The project work concerned with the selection of diamond wheel grit size relative to its grinding operations. Diamond grinding wheels are group of composite materials that are composed of diamond grits and a bonding matrix. The objectives are achieved by using Design Of Experiment (DOE) technique with two factors and three levels and the output quality consequences (Surface finish, Cycle time) are measured which are dependent on grit size & cutting feed. Experiments are conducted according to DOE technique on end mill in ANCA TX7+ CNC machine. Based on the experimentation grit size is standardized. The effectiveness of the approach is determined by factorial method of DOE, normality test and capability analysis with Minitab V17 for the individual grinding operations for end mill manufacturing.*

**Keywords***: End mill; Diamond wheel; Grit size; Grinding operations; Design of experiment; Minitab software.*

## 1. INTRODUCTION

Carbides are primarily used in finishing applications because of the its extreme hardness. Carbide also provides better rigidity than the other materials which enables the end mill to provide a high degree of dimensional accuracy and superior surface finishes. An end mill is a type of milling cutter which is used in various industrial milling applications. Grinding is the process of final finishing components required for smooth surfaces and close tolerances. It is widely used in various industry, grinding remain perhaps the least understood of all machining process[1]. Diamond wheels are grinding wheels with industrial diamonds bonded to the periphery. They are used for grinding hard materials. Wheel bond, how the wheel holds the abrasives, affects finish, and minimum/maximum wheel speed. Different wheel bonds available are Vitrified(V), Resinoid(B), Silicate(S), Shellac(E), Rubber(R), Metal(M), Oxychloride(O).

Manufacturing of end mill includes different grinding operations are Fluting, Gashing, Outer Diameter (OD) finish, and End face finish operation are shown in figure. Fluting (dark blue), refers to removal of material from a cylindrical surface usually creating helical or non-helical grooves. Gashing (dark pink), number of required short angular grooves ground on the start of flute face. OD finish (light blue), number of required axial cutting edges ground on the peripheral of fluted outer diameter. End face (yellow & light pink), number of required longitudinal cutting edges ground on the gashed front face.

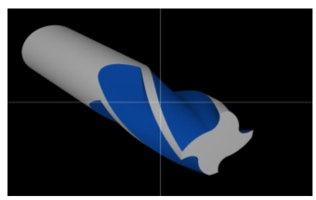

**Fig. 1: Fluting**

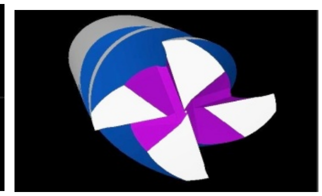

**Fig. 2: Gashing**

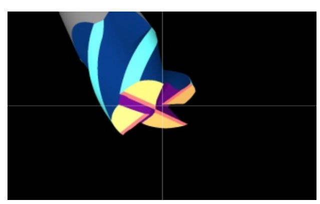

**Fig. 3: OD finish**

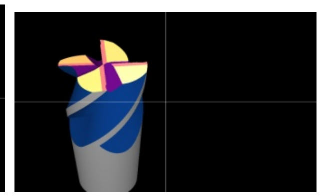

**Fig. 4: End face finish**

M. Ganesan et al. [1] used Taguchi's design of experiment to optimize the cylindrical grinding parameters for surface roughness. It is observed that good surface finish is obtained during the grinding process with optimum grinding conditions, cutting speed, feed rate, and depth of cut plays an important role in the cylindrical grinding parameters. Vulc. S et al.[2] presents a study of surface roughness carbide blanks DK460UF having composition of 91%WC and 9% Co. The samples tungsten carbides were machined with diamond grinding wheels with different grain size, with different cutting parameters, using cutting medium. The results of experimental studies have shown that machined surfaces of tungsten carbide by grinding have small roughness if it uses grinding wheel with optimum grit.

Snehil A Umerdkar [3] studied that the control parameters for grinding process are optimized for reduction in cycle time while maintaining quality standards in a bearing manufacturing company. Various control parameters consisting of feed parameters, position parameters, speed parameters were optimized and also the main parameters that affect the grinding process can be found out. K. Wegener [4] presents preparation of grinding tools & it influences the material removal rate, the surface quality as well as the material properties of the subsurface zone.

In our project work we used different diamond grits. Grain size determines the physical size of the abrasive grains in the wheel. A larger grain will cut freely, allowing fast cutting and gives poor surface finish. Fine grain sizes are used for precision finish work.

**Table 1: Diamond standard grit size**

| Diamond NORM FEPA | Micron Size (µm) |
|---|---|
| 10 | 6 – 12 |
| 15 | 10 – 20 |
| 20 | 15 – 25 |
| 25 | 20 – 30 |
| 30 | 22 – 36 |
| 35 | 30 – 40 |
| 46 | 38 – 45 |
| 54 | 45 – 53 |
| 64 | 53 – 63 |
| 76 | 63 – 75 |
| 91 | 75 – 90 |
| 107 | 90 – 106 |
| 126 | 106 – 125 |
| 151 | 125 – 150 |
| 181 | 150 – 150 |

## 2. PROBLEM IDENTIFICATION

The problem is identified in the grinding operation in end mill manufacturing is,

- Variation in surface finish
- Increasing cycle time

### 2.1 Objectives

- Standardization of diamond wheel grit size for different grinding operations
- The best resulted combination of DOE with the better surface finish, least cycle time will be selected and implemented in grinding operation.
- Improvement in productivity and quality.

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Process mapping

A high level process mapping for the existing process was made as shown in the figure.

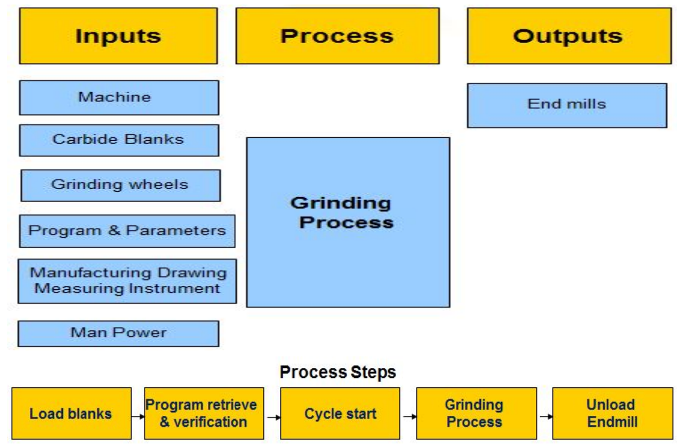


**Fig. 5: A high level process mapping**

### 3.2 Workpiece material

The workpiece material selected for study is carbide end mill, having following dimension.

| | |
|---|---|
| Diameter | 16 mm |
| Overall length | 89 mm |
| Length of cut | 32 mm |
| No of flutes | 4 |

**Fig. 6: Carbide end mill**

### 3.3 Machining Process

In grinding of end mill material removal plays an important role in producing better surface finish. The grinding process is performed on ANCA TX7+ CNC machine. The coolant TG250 is used to remove the large amount of heat produced during the grinding operation and also improves the surface finish of the machined workpiece. The actual working of grinding operation is shown below.


**Fig. 7: ANCA TX7+ CNC machine**

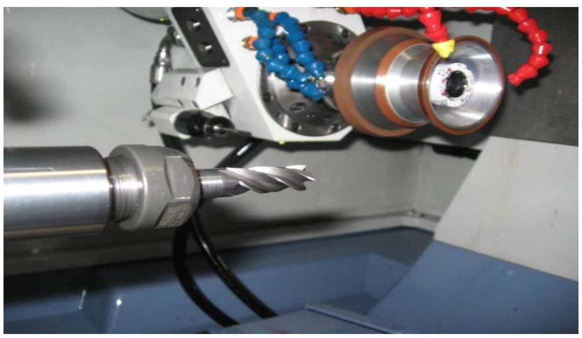

**Fig. 8: Grinding operation actual setup**

The experiments are conducted as per the Design of experiment technique and surface roughness of different combinations of parameters was measured using the Mahr surface roughness tester as shown below.


**Fig. 9: Mahr surface roughness tester**

## 4. DESIGN OF EXPERIMENT TECHNIQUE

Design of experiment (DOE) is a statistical tool for improving the product design and solving production problems [1]. It allows for multiple input factors to be manipulated determining their effect on a desired output (response). All possible combinations can be investigated (full factorial) or only a portion of the possible combinations (fractional factorial). DOE enhance the quality of product, process for the design and also reduce the cost.

In order to conduct the experiments different variables are to be considered. The variables considered are shown in the table below.

**Table 2: List of variables**

| **List of variables** |
|---|
| Concentration |
| Ø of wheel |
| Wheel shape |
| Wheel Bond |
| Bond Type |
| Wheel Manufacturer |
| Cutting speed |
| Grit size |
| Cutting Feed |

Different variables are involved to find the optimal value such as wheel concentration, Diameter of wheel, Wheel shape, Wheel bond, Bond type, Wheel manufacturer, Cutting speed, Grit size and Cutting feed. Brainstorming was done to identify key variables that affect the process. By studying all variables, finally potential causes were identified they are **Grit size** and **Cutting feed** that affect the grinding process.

**Table 3: Details of process parameters**

| **Common Variables - decided to keep as Constant Factors** | | | | |
|---|---|---|---|---|
| | **Fluting** | **Gashing** | **OD Finish** | **End Face** |
| Concentration | 100 | 100 | 100 | 125 |
| Ø of wheel(mm) | 125 | 125 | 125 | 75 |
| Wheel shape | 1V1 | 1V1 | 1A1 | 6A2 |
| Wheel Bond | Metal | Metal | Metal | R. Polymide |
| Bond Type | RM501 | RM515 | CB470 | B16 |
| Wheel Manufacturer | Toolgal | Toolgal | Toolgal | ASA |
| Cutting speed | 16 | 18 | 26 | 26 |

The output responses Surface finish (Ra), Cycle times (CT) are measured and standardized grit size for different grinding operations are determined by using Design Of Experiment (DOE) quality tool. Factorial method of DOE is used with two factors and three levels. Quality of the surface and cycle time depends on grit size & cutting feed used.

Total number of factors
2 Each at 3 levels
3 Total operations (Separate DOE)
4 Total number of experiments= $L^F*N$ 36

Where 'N' is the total No of operations

**Table 4: DOE matrix**

| | | | Levels (L) | | |
|---|---|---|---|---|---|
| | **Factors (F)** | **Total No Of Operations** | **L1** | **L2** | **L3** |
| A | Grit Size | Fluting | 64 | 91 | 126 |
| | | Gashing | 64 | 91 | 126 |
| | | OD Finish | 35 | 46 | 64 |
| | | End Face Finish | 54 | 64 | 76 |
| B | Cutting Feed (mm/min) | Fluting | 80 | 100 | 120 |
| | | Gashing | 30 | 45 | 60 |
| | | OD Finish | 80 | 100 | 120 |
| | | End Face Finish | 60 | 90 | 120 |

Since the focus is on standardizing of grit sizes for different operations without compromising on surface quality (Quality characteristic) and cycle time (Productivity characteristic), we have conducted all 36 experiments on the ANCA TX7+ CNC machine.

Factorial DOE for two factors and three levels is used in the present study.

**Table 5: Design of experiments & combinations**

| Fluting | | |
|---|---|---|
| DOE Combination | Grit Size | Cutting Feed |
| 1 | 64 | 80 |
| 2 | 64 | 100 |
| 3 | 64 | 120 |
| 4 | 91 | 80 |
| 5 | 91 | 100 |
| 6 | 91 | 120 |
| 7 | 126 | 80 |
| 8 | 126 | 100 |
| 9 | 126 | 120 |

| Gashing | | |
|---|---|---|
| DOE Combination | Grit Size | Cutting Feed |
| 1 | 64 | 30 |
| 2 | 64 | 45 |
| 3 | 64 | 60 |
| 4 | 91 | 30 |
| 5 | 91 | 45 |
| 6 | 91 | 60 |
| 7 | 126 | 30 |
| 8 | 126 | 45 |
| 9 | 126 | 60 |

| OD | | |
|---|---|---|
| DOE Combination | Grit Size | Cutting Feed |
| 1 | 35 | 80 |
| 2 | 35 | 100 |
| 3 | 35 | 120 |
| 4 | 46 | 80 |
| 5 | 46 | 100 |
| 6 | 46 | 120 |
| 7 | 64 | 80 |
| 8 | 64 | 100 |
| 9 | 64 | 120 |

| End Face | | |
|---|---|---|
| DOE Combination | Grit Size | Cutting Feed |
| 1 | 54 | 60 |
| 2 | 54 | 90 |
| 3 | 54 | 120 |
| 4 | 64 | 60 |
| 5 | 64 | 90 |
| 6 | 64 | 120 |
| 7 | 76 | 60 |
| 8 | 76 | 90 |
| 9 | 76 | 120 |

## 5. RESULTS & DISCUSSION

The selection of grit size and process variable is the important factor that affects the quality and surface finish of the work piece.

### 5.1 Design of Experiment best Combinations

Test for equal variances not done by Minitab software because, response samples are very less (minimum 32 samples required). The manual analysis has been made to identify the best combination with respect to Cycle Time (CT) & Surface finish (Ra).

- Lower the CT & lower the Ra is the best combination.

**Table 6: Best resulted DOE combinations**

| DOE Combination | **Fluting** Grit Size | Cutting Feed | No of pcs | Act Cycle Time | Surface Finish |
|---|---|---|---|---|---|
| 6 | 91 | 120 | 1 | 2.02 | 0.147 |
| | | | 2 | 2.02 | 0.141 |

| DOE Combination | **Gashing** Grit Size | Cutting Feed | No of pcs | Act Cycle Time | Surface Finish |
|---|---|---|---|---|---|
| 6 | 91 | 60 | 1 | 3.17 | 0.13 |
| | | | 2 | 3.17 | 0.129 |

| DOE Combination | **OD Finish** Grit Size | Cutting Feed | No of pcs | Act Cycle Time | Surface Finish |
|---|---|---|---|---|---|
| 6 | 46 | 120 | 1 | 2.33 | 0.149 |
| | | | 2 | 2.33 | 0.147 |

| DOE Combination | **End Face** Grit Size | Cutting Feed | No of pcs | Act Cycle Time | Surface Finish |
|---|---|---|---|---|---|
| 9 | 76 | 120 | 1 | 1.7 | 0.149 |
| | | | 2 | 1.7 | 0.15 |

The best resulted DOE combination (lower CT & Lower Ra) is given long run for 32 samples and it is analyzed using Minitab software.

### 5.2 Cycle time reduction

After implementing this project the cycle time is reduced from 11.3 min to 9.22 min.

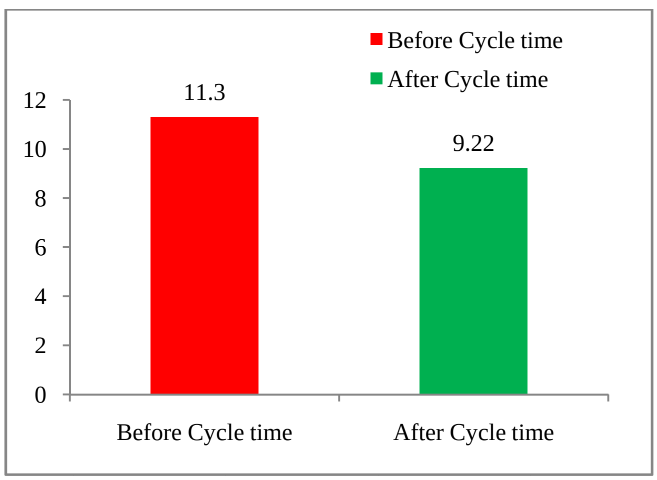


**Fig. 10: Cycle time reduction**

### 5.3 Analysis in Minitab software

All trails were entered into the Minitab V17 statistical analysis and output is obtained following the Normality and capability analysis for grinding of end mills. Normal distribution is followed and thers is no rejections (PPM=0) in the model and the process is capable since Cp value is above 1.3

### 5.3.1 Normality test

From Normality test we found that data follows normal distribution (p> 0.05) for each grinding operation.

- The process is in statistical control
- The distribution of the process considered is normal

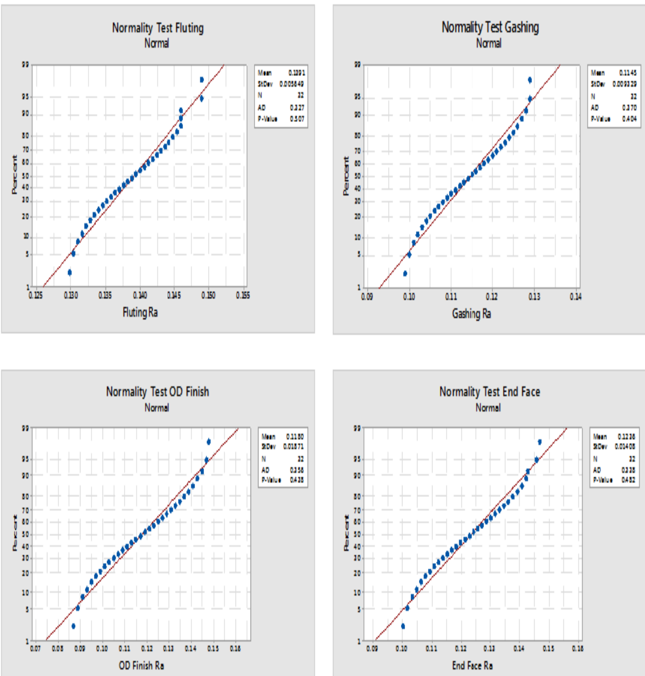


**Fig. 11: Normality test for each grinding operation**

### 5.3.2 Process capability

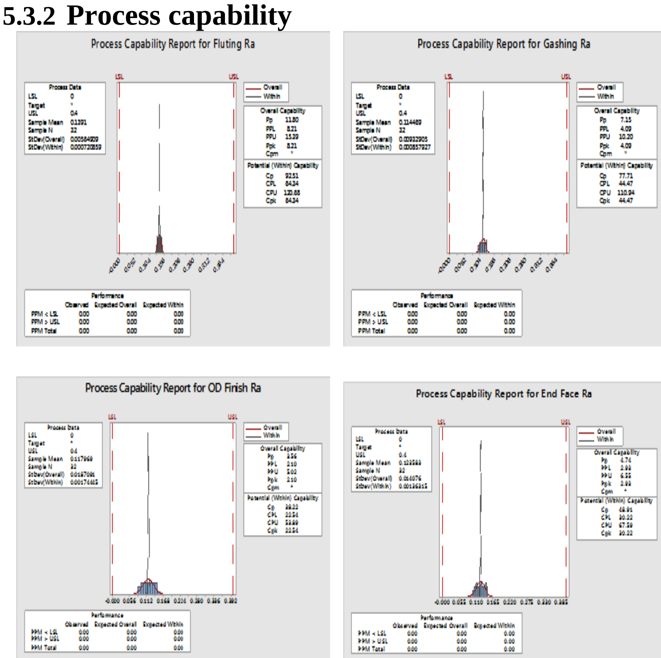


**Fig. 12: Process capability for each grinding operation**

For the surface roughness the USL is up to 0.4 Ra, the actual measurements of all 32 pieces were not deviated from the required specification (LSL=0, USL=0.4) and also there was no significant variation between the pieces produced in a same batch. So the quality yield has resulted more than 99.9997 percent for the Ra concerned in the process. It means there were no defects or opportunities in the produced batch with respect to surface roughness.

A process which produces less than 3.4 defects per million opportunities (DPMO) will have more than 6 sigma level process capability, by data it was found that the surface roughness process was having less than 3.4 DPMO, hence this process is stable or defects free, so automatically the process capability value will be highest & DPMO will be lowest.

## 6. CONCLUSION

On the basis of data analysis, the following conclusions can be drawn.

1. The experimental results will provide a standardized grit size for different grinding operations.

| Grinding operation | Grit size | Cutting feed (mm/min) |
|---|---|---|
| Fluting | 91 | 120 |
| Gashing | 91 | 60 |
| OD finish | 46 | 120 |
| End face | 76 | 120 |

2. Cycle time reduction by 18%
3. Increasing productivity by 4% per day
4. There are no rejections of samples.
5. Generally, improvements through reduced cycle time & better quality product will give annual benefits of $15929.

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