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# Selection Of The Orthogonal Array In Turning Of AISI D2 Steel

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***Abstract:***
*In this paper the selection process of the orthogonal array in turning of AISI D2 steel is discussed, the outermost 2 mm thick oxide layer was removed from the surface of all the specimens (D2 steel) by rough turning with PVD coated ceramic inserts. Longitudinal turning tests were conducted on the specimens held on rigid and high precision CNC lathe using coated ceramic inserts. Turning tests have been performed for various combinations of cutting speed, feed rate, and depth of cut. The design of experiments was based on Taguchi method. The average values of tool flank wear (VB) and surface roughness (Ra) were measured at the end of each experiment. The average flank wear was monitored with the help of a tool maker's microscope and surface roughness was measured with a surface roughness analyzer. The experiments were interrupted at regular intervals to record average values of tool flank wear and surface roughness of the machined surface. Each single pass was carried out over an axial cutting length of 190 mm. The experiment was terminated when either of the following two conditions was reached: Condition 1: VB≥200 μm; Condition 2: Ra ≥ 1.6 μm. For this case the Orthogonal Array of* $L\ (OA)_9\ (3)^3$ *has been selected, Where, 9 means number of trials, (3) means number of levels of each factor,* $(\ )^3$ *means number of factors.*

***Keywords** : AISI D2 steel, Tool wear, Taguchi method.*

## 1.Introduction

An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. Once the parameters are assigned to a particular column of the selected orthogonal array, the factors at different levels are assigned for each trial. Various benefits of orthogonal array as given below:

- Conclusions valid over the entire region spanned by the control factors and their settings.
- Large saving in the experimental effort.
- Analysis is easy.

To define an orthogonal array, one must identify:

- Number of factors to be studied.
- Levels for each factor.
- The specific two-factor interactions to be estimated.
- The special difficulties that would be encountered in running the Experiment.

## 2.Experimental Procedure

Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired value. These measures are called signal to noise ratios.

The signal to noise ratio provides a measure of the impact of noise factors on performance. The larger the S/N, the more robust the product is against noise. Calculation of the S/N ratio depends on the experimental objective**.** There are three categories of quality characteristics in the analysis of S/N ratio i.e. Bigger- the- better, Lower- the- better, Nominal- is- best. The greater S/N ratio corresponds to better quality characteristics.

- Bigger-the-Better

$$\frac{S}{N}_{(Bigger)} = -10 \log\left(\frac{\Sigma\left(1/y_i^2\right)}{n}\right) \qquad (1)$$

- Smaller-the-Better - This is usually the chosen S/N ratio for characteristics like "surface roughness, tool wear" etc. In these the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes

$$\frac{S}{N}_{(Smaller)} = -10 \log\left(\frac{\sum y_i^2}{n}\right) \quad (2)$$

- Nominal-is-Best -

$$\frac{S}{N}_{(Nominal)} = 10 \log\left(\frac{\bar{Y}^2}{s^2}\right) \quad (3)$$

$L_9$ Orthogonal Array- $(3)^3$ for Surface Roughness (Ra) and Tool Wear (Flank wear, VB)

| **Experiment** | **A** | **B** | **C** |
|---|---|---|---|
| | **Speed** | **Feed** | **D.O.C** |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

*Table 1: Taguchi's recommended orthogonal array design*

Experimental Orthogonal Array –$L_9$ OA $(3)^3$ for Surface Roughness (Ra) and Tool wear (Flank wear, VB)

| Experiment | A | B | C |
|---|---|---|---|
| | **Speed** | **Feed** | **D.O.C** |
| 1 | 130 | 0.05 | 0.10 |
| 2 | 130 | 0.1 | 0.25 |
| 3 | 130 | 0.15 | 0.40 |
| 4 | 155 | 0.05 | 0.25 |
| 5 | 155 | 0.1 | 0.40 |
| 6 | 155 | 0.15 | 0.10 |
| 7 | 180 | 0.05 | 0.40 |
| 8 | 180 | 0.1 | 0.10 |
| 9 | 180 | 0.15 | 0.25 |

*Table 2: Experimental orthogonal array*

Response Parameters for orthogonal array- OA $L_9$ $(3)^3$ Tool Wear (flank wear, VB)

| Experiment | A | B | C | R1 | R2 | R3 | Average | S/N |
|---|---|---|---|---|---|---|---|---|
| | **Speed** | **Feed** | **D.O.C** | | | | | |
| 1 | 1 | 1 | 1 | 125 | 115 | 125 | 121.67 | -41.72 |
| 2 | 1 | 2 | 2 | 110 | 105 | 100 | 98.33 | -39.87 |
| 3 | 1 | 3 | 3 | 100 | 100 | 120 | 106.67 | -40.62 |
| 4 | 2 | 1 | 2 | 150 | 140 | 150 | 163.33 | -44.27 |
| 5 | 2 | 2 | 3 | 125 | 130 | 115 | 123.33 | -41.83 |
| 6 | 2 | 3 | 1 | 140 | 130 | 125 | 131.67 | -42.40 |
| 7 | 3 | 1 | 3 | 145 | 150 | 160 | 151.67 | -43.63 |
| 8 | 3 | 2 | 1 | 160 | 170 | 160 | 163.33 | -44.29 |
| 9 | 3 | 3 | 2 | 175 | 220 | 210 | 201.67 | -46.13 |

*Table 3: Response (R1, R2, R3) & S/N Ratio*

*S/N ratio (lower is better) =* $-10\log_{10}\{1/n \sum y^2\}$

Response Parameters for orthogonal array- OA L9 $(3)^3$ Surface Roughness (Ra)

| Experiment | A | B | C | R1 | R2 | R3 | Average | S/N |
|---|---|---|---|---|---|---|---|---|
| | **Speed** | **Feed** | **D.O.C** | | | | | |
| 1 | 1 | 1 | 1 | 0.84 | 0.84 | 0.9 | 0.86 | 1.30 |
| 2 | 1 | 2 | 2 | 0.60 | 0.58 | 0.68 | 0.62 | 4.13 |
| 3 | 1 | 3 | 3 | 1.02 | 1.02 | 1.05 | 1.03 | -0.26 |
| 4 | 2 | 1 | 2 | 0.49 | 0.50 | 0.54 | 0.51 | 5.83 |
| 5 | 2 | 2 | 3 | 0.62 | 0.69 | 0.56 | 0.62 | 4.04 |
| 6 | 2 | 3 | 1 | 0.98 | 1.00 | 1.01 | 0.98 | 0.14 |
| 7 | 3 | 1 | 3 | 1.11 | 1.15 | 1.18 | 1.15 | -1.19 |
| 8 | 3 | 2 | 1 | 0.59 | 0.62 | 0.66 | 0.62 | 4.10 |
| 9 | 3 | 3 | 2 | 1.13 | 1.3 | 1.05 | 1.10 | -0.83 |

*Table 4: Response (R1, R2, R3) & S/N Ratio*

*S/N ratio (lower is better) =* $-10\log_{10}\{1/n \sum y^2\}$

Analysis of flank wear versus speed. Feed, DOC

| Level | Speed(A) | Feed(B) | DOC(C) |
|---|---|---|---|
| 1 | -41.74 | -42.20 | -41.80 |
| 2 | -42.33 | -41.00 | -44.42 |
| 3 | -44.68 | -43.05 | -41.03 |
| Max-min | 3.94 | 1.2 | 1.39 |
| Rank | 1 | 3 | 2 |

*Table 5: Response for Signal to Noise Ratios Smaller is better*

| Level | Speed(A) | Feed(B) | DOC(C) |
|---|---|---|---|
| 1 | 108.89 | 145.56 | 138.89 |
| 2 | 139.44 | 128.33 | 154.44 |
| 3 | 172.22 | 146.67 | 127.22 |
| Max-min | 63.33 | 18.34 | 27.22 |
| Rank | 1 | 3 | 2 |

*Table 6: Response for Means*

ANOVA results for flank wear (VB)

| | **Degree of freedom(DF)** | **Sum of squares** | **Mean square** | **F- ratio** | **Percentage (%)contribution of factors** |
|---|---|---|---|---|---|
| **Speed** | 2 | 23.35 | 11.67 | 8.28 | 73.65 |
| **Feed** | 2 | 2.59 | 1.30 | 0.92 | 8.18 |
| **DOC** | 2 | 2.94 | 1.47 | 1.04 | 9.28 |
| **Error** | 2 | 2.82 | 1.41 | | 8.90 |
| **Total** | 8 | 31.69 | | | |

*Table 7: ANOVA results for flank wear*

Main Effects Plot for S/N ratios for Tool wear (Flank wear, VB)

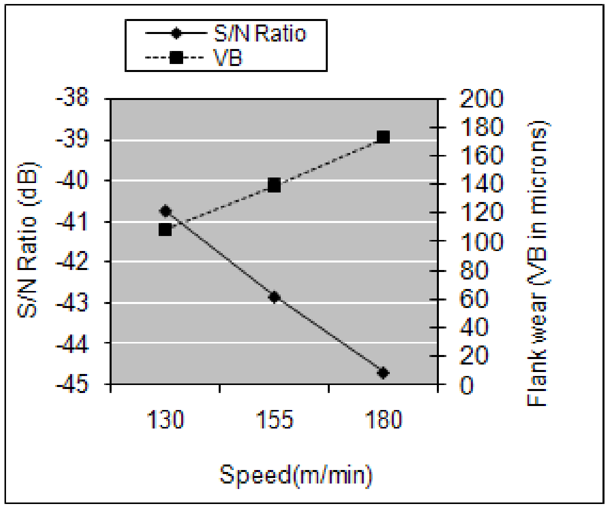


*Figure 1: S/N Ratio values for speed*

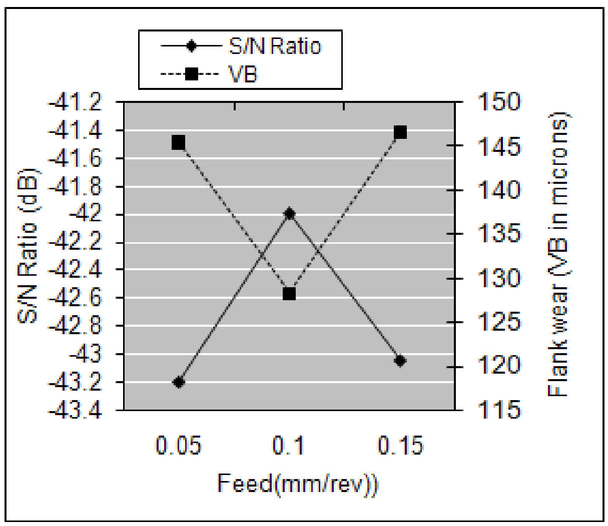


*Figure 2: S/N Ratio values for feed*

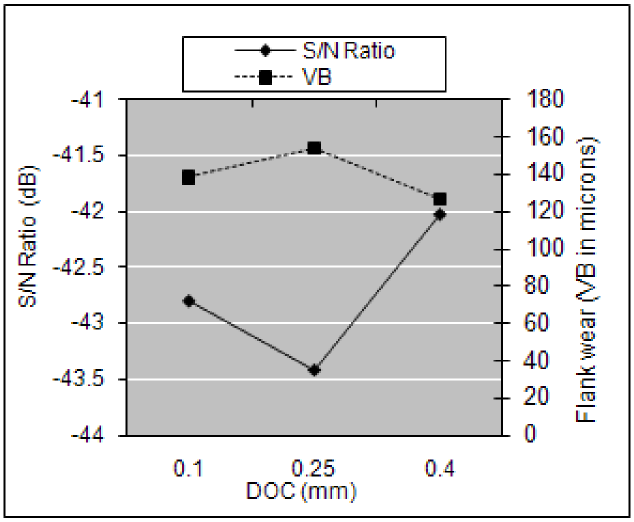


*Figure 3: S/N Ratio values for DOC*

Analysis of Ra versus Speed, Feed, DOC

| Level | Speed | Feed | DOC |
|---|---|---|---|
| 1 | 1.7352 | 1.9900 | 1.8539 |
| 2 | 3.3667 | 4.1211 | 3.0576 |
| 3 | 0.6963 | -0.3129 | 0.8867 |
| Max-min | 2.6704 | 4.4340 | 2.1709 |
| Rank | 2 | 1 | 3 |

*Table 8: Response for Signal to Noise Ratios Smaller is better*

| Level | speed | Feed | DOC |
|---|---|---|---|
| 1 | 0.8367 | 0.8389 | 0.8222 |
| 2 | 0.7056 | 0.6222 | 0.7433 |
| 3 | 0.9567 | 1.0378 | 0.9333 |
| Max-min | 0.2511 | 0.4156 | 0.1900 |
| Rank | 2 | 1 | 3 |

*Table 9: Response for means*

| | Degree of freedom(DF) | Sum of square S | Mean square | F ratio | Percentage of contribution (%) |
|---|---|---|---|---|---|
| **Speed** | 2 | 10.69 | 5.35 | 1.34 | 19.47 |
| **Feed** | 2 | 29.10 | 14.55 | 3.63 | 52.98 |
| **DOC** | 2 | 7.13 | 3.57 | 0.89 | 12.98 |
| **Error** | 2 | 8.01 | 4.00 | | 14.58 |

*Table 10: ANOVA results for surface roughness*

Main Effects Plot for S/N ratios for Surface Roughness

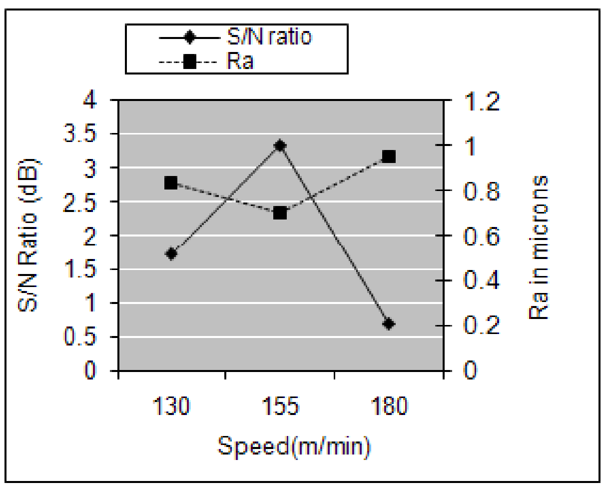


*Figure 4: S/N Ratio values for speed*

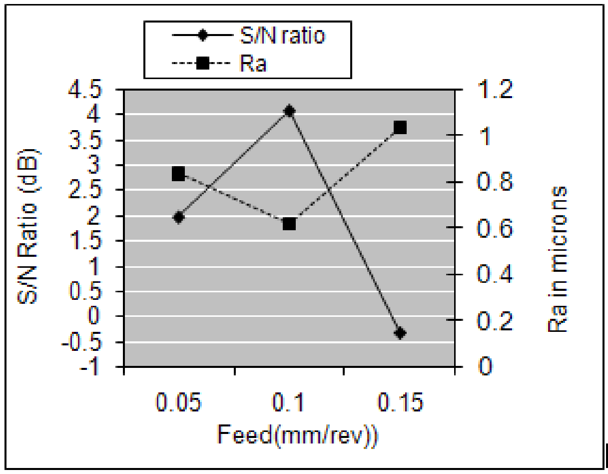


*Figure 5: S/N Ratio values for feed*

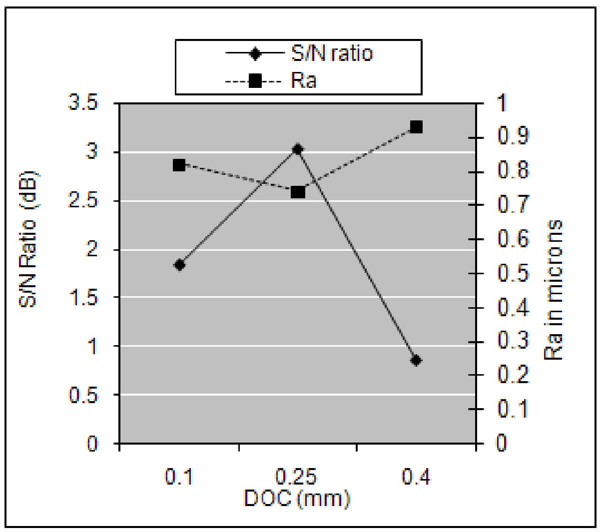


*Figure 6: S/N Ratio values for D.O.C*

**3.Result**

The S/N ratios for VB Vs. speed and D.O.C (Main effects) are given in Table 5-6 and S/N ratios (Main effects) for Ra Vs. feed and D.O.C is given in Table 8-9. The speed and the depth of cut are two factors that have the highest difference between values (Max.-Min.) 63.33 and 27.22 for tool wear (flank wear), 4.4340 and 2.6704 for surface roughness (Ra) respectively. Based on the Taguchi prediction larger difference between values of S/N ratio, will have a more significant effect on tool wear and surface roughness (Ra). Thus, it can be concluded that increasing the speed will increase the tool

wear (flank wear-VB) significantly and also the depth of cut. The Surface roughness (Ra) will be increased by increasing the feed rate significantly and also speed. Fig. 1 shows that increase in speed reduces S/N ratio thus tool wear increases with increase in speed and fig. 4 shows that at some increase in speed surface roughness reduces but after that it starts increasing. Fig. 2 shows that flank wear reduces upto a certain limit by increasing feed but after that tool wear increases and fig 5 shows that upto some value of feed rate surface roughness reduces but after that surface roughness starts increasing. Fig. 3 shows that flank wear increases with increasing in depth of cut but after some value flank wear starts reducing and fig. 6 shows that surface roughness surface level reduces upto a certain level of D.O.C. after that surface roughness starts increasing.
The optimal setting of parameters obtained from main effects plot is given below:

| Optimal parameters | Speed m/min | Feed mm/rev. | D.O.C mm |
|---|---|---|---|
| Flank wear(VB) | 130 | 0.1 | 0.4 |
| Surface roughness (Ra) | 155 | 0.1 | 0.25 |

*Table 11: Optimal parameters for Ra and VB*

**4.Conclusion**

Conclusion: PVD coated ceramic tools employed in current investigation have been observed to be an economical alternative to costly CBN and carbide tools, for continuous hard turning application, over the range of parameters selected for this study. The percentage contribution of input parameters on flank wear (VB) is: Speed = 76.55%, Feed rate = 9.18% and D.O.C. =8.28%, signifying the cutting speed to be the most contributing factor influencing Flank wear. The percentage contribution of input parameters on Surface roughness (Ra) is: Speed = 19.47%, Feed rate = 52.98% and D.O.C. =12.98%, signifying the feed rate to be the most contributing factor influencing Surface roughness. The optimized machining conditions for minimizing tool wear from Taguchi analysis are approaching: cutting speed 130 m/min., feed 0.10 mm/rev., depth of cut 0.40 mm with an estimated flank wear 96 µm. The optimized machining conditions for minimizing tool wear from Taguchi analysis are approaching: cutting speed 155 m/min., feed 0.10 mm/rev., depth of cut 0.25 mm with an estimated surface roughness of 0.57 µm.

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