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# OPTIMIZATION AND ANALYSIS OF CUTTING PARAMETERS USING CRYOGENIC MEDIA IN MACHINING OF HIGH STRENGTH ALLOY STEEL

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## ABSTRACT

In this research, liquid Argon is used as a cryogenic media to optimize the cutting parameters for evaluation of tool flank wear width of Tungsten Carbide Insert (CNMG 120404-WF 4215) while turning high strength alloy steel. Robust design concept of Taguchi L9 (34) method is applied to determine the optimum conditions. This analysis revealed is revealed that cryogenic impact is more significant in reduction of the tool flank wear.

**Keywords**: turning, liquid argon, flank wear.

## 1 INTRODUCTION

The adoption of sustainability in machining processes is more an environmental concern than a technical or financial aspect. Still the industry uses various cutting oils /emulsions as cutting fluids, even though they pose environmental and health hazards (Kopac 2009). However, cryogenic gases rapidly evaporate in the atmosphere without leaving any residue to contaminate the environment (Umbrello, Micar and Jawahir 2012). They also have the ability to penetrate rapidly in tool-chip interaction while machining as compared to cutting oils/emulsions (Shaw 1986; Adler *et al.* 2006). In this study, four types of cryogenic methods are to be applied to evaluate the results in machining process namely: (a) Cryogenic pre-cooling the work-piece, (b) Indirect cryogenic cooling, (c) Cryogenic spraying and jet cooling and (d) Cryogenic Treatment

## 2 CRYOGENIC JET COOLING AND TOOL LIFE

Cryogenic jet cooling is the most effective and economical way to control temperature of tool-chip contact while machining (Yildiz and Nalbant 2008). In flood / spray cryogenic cooling, cutting force is increased which is adversely affected by the life of a tool (Zurecki, Ghosh and Frey 2003). Consumption rate can be made efficient by applying micro nozzles nearby the desired face of a tool

(Hong, Ding and Jeong 2001). Concept of sustainability regarding production cost may be achieved through this way (Hong 1995) and a phenomenon of BUE may be reduced due to low temperature and high pressure developed through jet nozzle (Hong 2001). The cutting temperature of rake & flank face was found to be lower in the case of cryogenic cooling using liquid nitrogen and different cooling configurations (Hong and Ding 2001). About 150 % increase in tool life was reported while cryogenic machining of Steel AISI 1060 through SNMG inserts as compared to dry and wet. (S. Paul, Dhar, Chattopadhyay 2001, Dhar et al 2006). It was also reported tool life has been improved almost two to three times for carbide inserts on steel AISI1040 (Dhar, Paul and Chattopadhyay 2002). Reducing of flank wear by SNMM insert was attributed to its geometric structure having deep grooves parallel to the cutting edges helping entry of larger fraction of the liquid nitrogen jets at the flank surfaces (Dhar, Kamruzzaman 2007; Dhar, Paul and Chattopadhyay 2002).

## 3 EXPERIMENTAL PROCEDURE

All experiments were conducted using test pieces of Ø85 x 150 mm. The chemical composition is given in Table 1. The samples were normalized at 920°C and maximum hardness was 20HRC. CTX 510 eco Turning machine with tool holder PCLNL 2525 M12 has been used to evaluate the tool life of Sandvik Coromant inserts (CNMG 120404-WF 4215) as per ISO standard 3685:1993(E). Experiments with Liquid Argon have been carried out with an outlet diameter 1.2mm jet nozzle at 4.0 bar pressure. Microscope OPTIKA® at magnification of 20 is used to measure the flank wear width.

Table 1: Chemical composition of alloy steel.

| C | Si | Mn | Ni | Cr | P | Cu | V | Mo | S |
|---|---|---|---|---|---|---|---|---|---|
| .27~.32 | 1.4~1.7 | .7~1 | <0.25 | 1~1.3 | <.015 | <0.25 | 0.08~.15 | .4~.55 | <0.01 |

### 3.1 Taguchi Method

The robust methodology of Taguchi analyzes the entire parameter space only with a small number of experiments. Orthogonal array L9 ($3^4$) is used to analyze the effect of machining parameters with an assumption that no interaction exists between the machining parameters. Machining parameters and their levels are given in Table 2. The experimental layout L9 (34) with responses, mean value of responses and their respective Signal to Noise (S/N) ratio by using eq. (1) is given in table 3(M. S. Phadke 2007). Lower the better type of response is used (Brij *et al* 2012) which is given by the following equation:

$$S/N = -10 log\left[\frac{(\sum_{i=1}^{n} Y_i^2)}{n}\right] \tag{1}$$

Here, $n$ represents the trial conditions and $Y_1$, $Y_2$ ,$Y_3$, ..........$Y_n$ represents the values of responses for quality characteristics.

Table 2: Machining parameters and their levels.

| Factor Code | Process Parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| A | Depth of Cut (DOC) | 1 | 1.5 | 2 |
| B | Feed Rate | 0.05 | 0.10 | 0.15 |
| C | Cutting Speed (Vc) | 220 | 280 | 340 |
| D | Cooling Media | Dry | Emulsion Oil | Liquid Argon |

Table 3: L9 ($3^4$) orthogonal array with responses, their means and S/N ratios.

| Run | DOC [mm] | Feed [mm/rev] | $V_C$ [m/min] | Cooling Media | Trial 1 $VB_B$[μm] | Trial 2 $VB_B$[μm] | Mean $VB_B$[μm] | S/N Ratio $\eta_i$ [dB] |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.05 | 220 | DRY | 21.3 | 30.8 | 26.05 | -28.3162 |
| 2 | 1 | 0.10 | 280 | ON | 16.6 | 21.3 | 18.95 | -25.5522 |
| 3 | 1 | 0.15 | 340 | L.Ar | 23 | 22.2 | 22.6 | -27.0822 |
| 4 | 1.5 | 0.05 | 280 | L.Ar | 22.2 | 23.5 | 22.85 | -27.1777 |
| 5 | 1.5 | 0.10 | 340 | DRY | 30.3 | 63.3 | 46.8 | -33.4049 |
| 6 | 1.5 | 0.15 | 220 | ON | 26.5 | 33.3 | 29.9 | -29.5134 |
| 7 | 2 | 0.05 | 340 | ON | 30.3 | 27.7 | 29 | -29.248 |
| 8 | 2 | 0.10 | 220 | L.Ar | 21.3 | 12.5 | 16.9 | -24.5577 |
| 9 | 2 | 0.15 | 280 | DRY | 27.3 | 47.9 | 37.6 | -31.5038 |

## 3.2 Selection of Optimal Levels

The main effects of each machining parameters (Tyagi *et al* 2012) at different levels are calculated and given in Table 4.Similarly, the same is graphically represented in Fig.1 by using Minitab15. It is clearly showed that, optimum value can be achieved through applying level $A_1B_2C_1D_3$ *(1, .10, 280, L.Ar).*

Table 4: Average signal to noise ratio (S/N) for different factor levels.

| Process Parameters | | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| **A** | Depth of Cut(mm) | **-26.9835** | -30.032 | -28.4365 |
| **B** | Feed(mm/rev) | -28.2473 | **-27.8383** | -29.3664 |
| **C** | Speed(m/min) | **-27.4624** | -28.0779 | -29.9117 |
| **D** | Cooling Media | -31.0749 | -28.1045 | **-26.2725** |

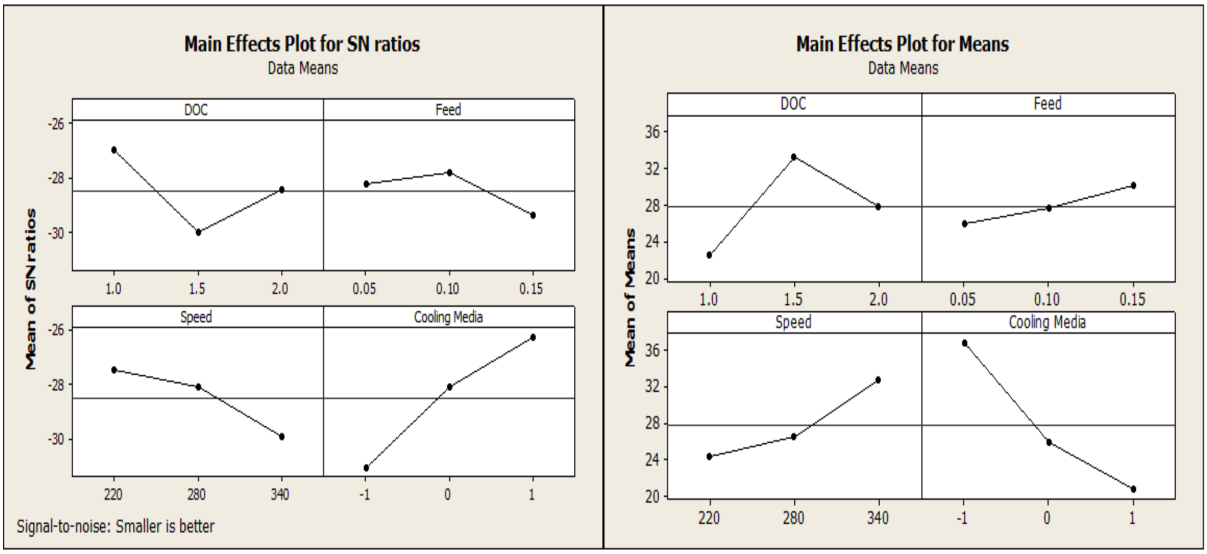


Figure 1: Average values for tool wear.

## 4 ANALYSIS OF VARIANCE

The purpose of the Analysis of Variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. Results of the Analysis of Variance carried out for the experimental plan is presented in Table 5.

Table 5: Analysis of variance for mean tool flank wear width.

| Parameters | DOF | SS | MS | F Ratio | P Value | Contribution% |
|---|---|---|---|---|---|---|
| DOC | 2 | 13.95 | 6.98 | 3.72 | 0.212 | **22.3** |
| Feed | 2 | 3.76 | 1.88 | - | - | 6 |
| Speed | 2 | 9.74 | 4.87 | 2.59 | 0.278 | 15.5 |
| Coolant | 2 | 35.24 | 17.62 | 9.39 | 0.096 | **56.2** |
| Residual | 0 | 0 | - | - | - | - |
| Total | 8 | 62.69 | 31.34 | - | - | 100 |
| (Residual) | (2) | (3.76) | (1.88) | - | - | |

**4.1 Estimation of Predicted Mean Tool Flank Wear Width at the Optimal Condition.** The estimated S/N ratio $\eta_{opt}$ using the optimal level of the design parameters (Phadke 2007) can be calculated as:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{q}(\eta_i - \eta_m) \quad (4)$$

where $\eta_m$ is the total mean S/N ratio, $\eta_i$ is the mean S/N ratio at the optimal level, and q is the number of the main design parameters that affect the quality characteristic. Therefore, $\eta_{opt}$ = -23.7505dB, by using eq. (1), we can predict the optimum value of tool flank wear width i.e 11.90 µm

**4.2 Confirmations Run.** Confirmation run has been conducted at the achieved optimal level *$A_1B_2C_1D_3$ (1, .10, 280, L. Ar)*.While machining, the maximum tool flank wear width was found to be 13.25 µm as shown in Fig.2. The result is very close to the predicted value. The 0.8072 dB improvement in S/N ratio has been achieved. Tool wear is decreased by 3.65 µm.

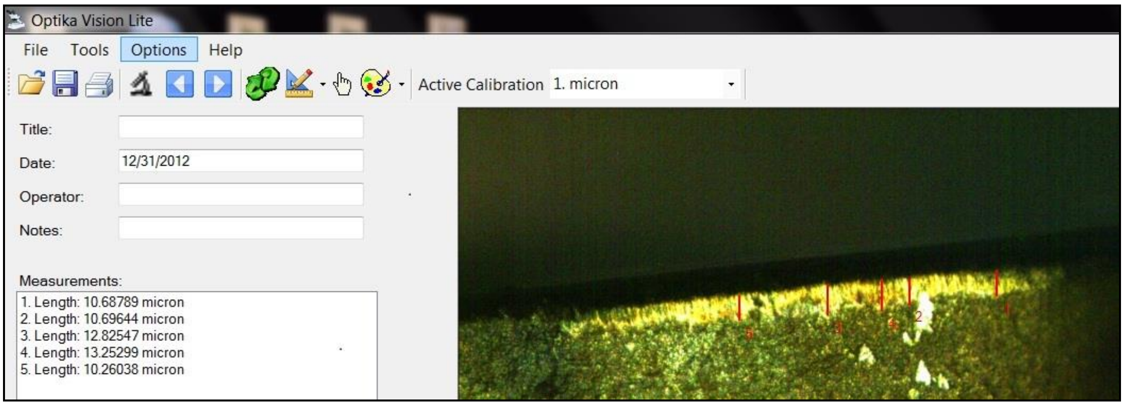


Figure 2: Measurement of tool flank wear.

## 5 CONCLUSIONS

- Parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the machining parameters.
- The experimental results demonstrate that the *Cooling Media and depth of cut* are the main parameter among the four controllable factors (DOC, Feed , Speed and cooling Media) that influences the flank wear in machining of alloy steel.
- Main effect plots show the significant impact of cryogenic fluid on the tool life. Tool wear is reduced by 43.5% as compared to dry machining and is reduced by 19.9% as compared to emulsion oil.
- Optimal machining parameters *$A_1B_2C_1D_3$ (1, 0.10, 280, L.Ar)* are recommended to minimize the wear rate. By applying these, the tool flank wear is decreased by *21.8 %*

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