Cermet for Turning Hardened Steel

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Abstract. This study deals with an effort to assess the performance of Cermet cutting tool as an alternative cutting tool for turning hardened steel. Some machinability aspects, including tool wear, cutting time, surface finish, and optimum cutting condition were assessed. The experiment was carried out by adopting Taguchi method (L8) and Taguchi signal-noise (S/N) ratios was utilised to determine the optimum cutting condition. Flank wear was observed as the main tool failure mode. Related to flank wear, the Cermet cutting tool used in this study had potential cutting time when assigned for hard turning. Surface finish measured under Ra parameter for all tested cutting conditions was at the quality of finish turning. The statistical analysis supported the engineering perspective to define surface finish as the main response variable to be used for the evaluation of optimum cutting condition. The result of Taguchi S/N analysis on the optimum cutting condition showed a good agreement with the experiment.

1. Introduction
Maintaining the sustainability and avoiding the supply shortage of the most demand cutting tool material made of cemented carbide (WC-Co) were background of study [1]. The study reported in this paper was focused on an effort to assess the performance of Ceramic Metal (Cermet) as an alternative of cutting tool for turning hardened steel. The assessment deals with machinability aspects, including tool wear, cutting time, surface finish, and optimum of cutting condition.

The studies on the application of Cermet for hard machining were still limited with the in-house development Cermet cutting tool. Yang et al. [2], developed Cermet made of (Ti₀.₅, W₀.₅) C-15%wt Co and enriched with (5-20) % of Mo₂C as a binder. They used this cutting tool of Cermet for hard turning of VDEH90CrSi₅ steel (62 HRC). Cermet cutting tool with 15% and 20% of Mo₂C met the expectation where abrasive and diffusive wear could be hindered. The study was continued and reported in [3]. Cutting conditions were varied at cutting speed of (180-450) rpm, feed of (0.8-0.20) mm/rev, and depth of cut of (0.2-0.5) mm. From the study, they concluded that Cermet cutting tool with 15% of Mo₂C was the best due to high cutting capability. In another study [4], it was reported that Ti(CN)-based Cermet providing tool longer life than Cemented Carbide Coated (TiCN/Al₂O₃/TiN) when applied for hard turning of steel (62 HRC) at cutting speed of (60-80) m/min, feed of 0.1 mm/rev, and depth of cut of 0.2 mm. In the case of roughness surface; however, Cermet produced higher Ra value than Coated Cemented Carbide. Catastrophic chipping and Flank wear were reported as failure mode the main of Cermet cutting tool when applied for hard turning.
2. Experimental setups
In this study, a commercial Cermet cutting tool with production code SNMG120408 grade CT5015 was selected. The titanium carbonitride (TiCN) was the core of Cermet cutting tool used in this study. This modern Cermet cutting tool was enhanced with (Ti, Nb, W) (C, N) for its second hard phase, and enriched with W-Co binder [5]. During turning test, the cutting tool was mounted on a tool holder coded MSDNN 2020 K12 and thus, the geometry of Cermet cutting tool became +45° (major cutting angle), +6° (clearance angle), -6° (inclination angle), and -6° (back rake angle).

For material workpiece, the high strength low alloy AISI 4340 was selected and prior to turning test, the heat treatment process was carried out by our industrial partner for the purpose of increasing the material hardness up to 50 HRC.

Table 1. Chemical composition (wt\%) of AISI 4340.

| Element | C | Ni | Mn | Mo | Si | Cu |
|---------|---|----|----|----|----|----|
|        | 0.410 | 1.790 | 0.650 | 0.220 | 0.220 | 0.050 |
|        | P | V | S | Al | Cr | Fe |
|        | 0.015 | 0.020 | 0.006 | 0.021 | 0.790 | rest |

Table 2. Mechanical properties of AISI 4340.

| Property          | Value       |
|-------------------|-------------|
| Density           | kg/m³       |
| Elasticity        | kN/mm²      |
| Poisson ratio     | -           |
| Tensile strength  | N/mm²       |
| Expansion         | m/m·°C (10⁻⁶) |
| Conductivity      | W/m·°C     |
| Specific heat     | J/kg·°C    |

The turning experiment was done by using a machine CNC lathe tool with maximum speed of 5000 rpm and 9.5 kW of motor. The measurement of tool wear was done by using a Dino-lite digital microscope AM 4515. For surface finish, Ra parameter was selected, and the measurement of roughness was taken by using Surftest SJ-210 unit.

2.1. Design of Experiment
The experiment was designed by adopting Taguchi method [6]. The detail of independent variables, levels, and values are given in Table 3. Taking the recommendation of tool manufacturer and the cutting condition of the previous researchers [2-4], the values in Table 3 were defined. As optimum cutting condition was concerned, Taguchi Signal-Noise (S/N) ratio was utilized for finding the optimum cutting condition which respected to response variables, i.e. tool wear, cutting time, and surface finish (roughness in Ra parameter). The analysis and measurement technique for tool wear was referred to ISO Standard 3685 [7]. Turning test was carried out with cutting length of 200 mm for each cutting condition and the cutting time was recorded.

Table 3. Design of experiment Taguchi L8 (4x2x2).

| Variable      | Unit | Code | Level 1 | Level 2 | Level 3 | Level 4 |
|---------------|------|------|---------|---------|---------|---------|
| Cutting speed | m/min| v    | 70      | 90      | 110     | 130     |
| Feed          | mm/rev| f    | 0.1     | 0.2     | -       | -       |
| Depth of cut  | mm   | a    | 0.1     | 0.2     | -       | -       |
3. Results and Discussion

3.1. Tool Wear, Cutting Time and Surface Roughness

The results of experiment concerning cutting conditions and response variables are given in Table 4. The data indicates that the turning test has been successfully carried out at the defined cutting conditions. After turning for cutting length of 200 mm, the longest cutting time recorded was 7.23 minutes (run 1), the highest flank wear width (VB) was 110 microns (run 8), and the lowest surface roughness (Ra) was 0.410 microns (run 7).

Table 4. Experimental data.

| Run | Cutting condition | Cutting time (CT) (min) | Flank Wear (VB) (micron) | Surface Roughness (Ra) (micron) |
|-----|-------------------|-------------------------|--------------------------|-------------------------------|
| 1   | 70.00 0.10 0.10   | 7.23                    | 71                       | 0.994                         |
| 2   | 70.00 0.20 0.20   | 3.62                    | 83                       | 1.964                         |
| 3   | 90.00 0.10 0.10   | 6.19                    | 79                       | 0.815                         |
| 4   | 90.00 0.20 0.20   | 2.59                    | 91                       | 1.695                         |
| 5   | 110.00 0.10 0.20  | 4.31                    | 86                       | 0.479                         |
| 6   | 110.00 0.20 0.10  | 2.42                    | 102                      | 2.293                         |
| 7   | 130.00 0.10 0.20  | 3.28                    | 94                       | 0.410                         |
| 8   | 130.00 0.20 0.10  | 1.39                    | 110                      | 2.224                         |

From the measurement of tool wear resulted by each run, it was flank that observed wear was the main tool failure/wear mode for Cermet cutting tool used in this study. The example of flank wear generated during turning test is given in Figure 1. In the figure, it can be observed the situation of tool wear produced after turning length of 200 mm under cutting speed (v) of 130 m/min, feed (f) 0.20 mm/rev, and depth of cut (a) of 0.1 mm. As mentioned in Table 4, the flank wear width (VB) shown in Figure 1 was recorded at 110 microns.

![Figure 1. Flank wear situation produced after turning test run number 8 (see Table 4).](image)

3.2. Statistical Analysis

3.2.1. Probability plot. Prior to determine the optimum cutting condition that respected to those response variables in this study, all observation data in Table 4 were statistically analysed. The first analysis was done by the probability plot as shown in Figures 2. The AD and P-values of those plots in Figure 2 indicate a good fit or the experimental data are normally distributed and thus, those data are reasonable to be used for optimisation.
3.2.2. **Analysis of Variance (ANOVA).** The results of ANOVA analyses for those response variables (tool wear, cutting time, and surface roughness) had been done. The results show that the significant effect (from the highest to the lowest contribution) of independent variables to response variables are: (1) for tool wear: v, f, and a, (2) for cutting time: f, v, and a, and (3) for surface roughness: f, a, and v.

### Table 5. ANOVA for response variable surface roughness (Ra).

| Source | DF | Seq SS  | Contribution | Adj SS  | Adj MS  | F-Value | P-Value |
|--------|----|---------|--------------|---------|---------|---------|---------|
| v      | 3  | 0.05542 | 1.32%        | 0.05542 | 0.01847 | 18.24   | 0.052   |
| f      | 1  | 3.75106 | **89.23%**   | 3.75106 | 3.75106 | 3704.75 | 0.000   |
| a      | 1  | 0.39516 | 9.40%        | 0.39516 | 0.39516 | 390.28  | 0.003   |
| Error  | 2  | 0.00202 | 0.05%        | 0.00202 | 0.00101 |         |         |
| Total  | 7  | 4.20366 | 100.00%      |         |         |         |         |

These results show that feed (f) is dominantly affected the response variables. From manufacturing engineering/metal cutting perspective, the dominant effect of feed (f) indicates that the Cermet cutting tool used in this study is suitable only for finish cutting or finish operation when turning of hardened AISI 4340 steel. Consequently, surface roughness would be the main response variable to be used for the evaluation of optimum cutting condition. The ANOVA for surface roughness is given in Table 5.
3.3. Optimum Cutting Condition
Taguchi S/N ratios technique was utilised to determine the cutting condition optimum. Concerning the result of ANOVA and engineering consideration where the suitability of the cutting Cermet tool used in this study was at finish turning; therefore, the characteristic of S/N analysis was at smaller-the-better. In finish turning, the lower the Ra value the better is the quality of surface finish. The result of S/N analysis for surface roughness is presented in Figure 3. From the figure, the optimum cutting condition is at cutting speed (v) of 130 m/min, feed (f) of 0.1 mm/rev, and depth of cut (a) of 0.2 mm. This S/N analysis has a good agreement with the result of experiment. The cutting condition optimum was given by run number 7 (see Table 4) in which surface roughness (Ra value) was at 0.410 microns or the lowest among all tested cutting conditions. Figure 4(a) and 4(b) show the position of the cutting condition optimum that is at the low left corner of the surface contours.

![Main Effects Plot for S/N ratios of response variable surface roughness (Ra).](image)

**Figure 3.** Main effects plot for S/N ratios of response variable surface roughness (Ra).

![Surface Plot of surface roughness vs cutting speed, feed](image)

(a)

![Surface Plot of surface roughness vs depth of cut, feed](image)

(b)

**Figure 4.** Surface plot of surface roughness versus: (a) cutting speed and feed, and (b) depth of cut and feed.

4. Conclusions
The assessment of performance of Ceramic Metal (Cermet) as an alternative cutting tool for turning hardened AISI 4340 steel (50 HRC) had been carried out successfully. Some machinability aspects were assessed, including tool wear, cutting time, surface finish, and optimum cutting condition. Flank wear was observed as the main failure/wear mode of the Cermet cutting tool. The flank wear was noted within the tool nose region since the suitable values of feed and depth of cut were less than the tool nose radius ($r_e$ 0.8 mm). From the relation between flank wear width and cutting time, it could be concluded that
the Cermet cutting tool has potential time tool service (tool life) for finish operation of hard turning. All tested cutting conditions generate good surface finish (finish quality). The statistical analysis supports the engineering perspective to define surface roughness as the main response variable to be used for the evaluation of cutting condition optimum. Taguchi S/N ratios analysis at the smaller-the-better showed that cutting condition optimum was at cutting speed (v) of 130 m/min, feed (f) of 0.1 mm/rev, and depth of cut (a) of 0.2 mm. This S/N analysis showed a good agreement with the result of experiment.

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