When Cermet Applied for Hard Machining of Steel: A Review

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Abstract. Providing an information deals with the application of Ceramic Metal (Cermet) as a cutting tool applied for hard machining of steel is the objective of this review paper. Cermet is made of hard metals and was introduced just after the invention of Cemented Carbide. As a cutting tool, the conventional Cermet was known as TiC-based Cermet. Unfortunately, it was not as successful as Cemented Carbide due to its brittleness of low fracture toughness of TiC substrate. Thanks to TiN material. The addition of TiN improved the fracture toughness, and the modern era of Cermet was begun. A TiCN-based modern Cermet is characterized microstructurally by a structured hard phase featuring core-rim structure embedded in a tough Co-Ni binder. The effort to refine the fracture toughness of TiCN Cermet is discussed in this paper including the effort to raise its performance through coating technologies. In particular, its performance which is given in term of productivity and represented by volume of removal rate (VMR) is discussed. Finally, conclusions and recommendation for future works are written.

1. Introduction
The application of Ceramic Metal (Cermet) cutting tool for hard machining of steel is reviewed and reported in this paper. Hard machining technology and its background are explained briefly and the important of cutting tool made of hard metal (cemented carbide and cermet) for hard machining is studied. Moreover, the study related to improve the intrinsic factor of Cermet is also briefed. Some machinability factors to govern the performance of Cermet is evaluated. Finally, performance of Cermet as cutting tool for hard machining is resumed in term of productivity.

Since 1980s, hard machining technology has been applied in machining of hardened ferrous metal for the ultimate goal of efficiency and productivity. Before the implementation of hard machining, grinding operation was the machining technique for processing of hardened ferrous steel. In grinding operation, efficiency and productivity were lower than hard machining due to longer setup time, lower metal removal rate, and investment of grinding tools. Those were finally impacted production time and cost.

At the beginning of technology implementation, Konig et al. [1] reported the fundamental theory and application of hard machining comprehensively. It was reported that hard machining technology had successfully been implemented in cutting of ferrous alloys in its their hardened condition (50-70 HRC). To ensure the success of hard machining process, there were 3 (three) aspects had to be taken into account, i.e. (1) adequate cutting tool material, (2) a rigid, high precision, and sufficient power machine
tool, and (3) proper setup and suitable cutting condition. For cutting tool material, the cutting tools made of cubic boron nitride (CBN), ceramics, and cemented carbide were highly recommended. Based on the performance of the cutting tools, CBN was recommended for ferrous metal with high hardness of (63-70) HRC, ceramic for the hardness up to 63 HRC, and cemented carbide was assigned for the hardness up to 58 HRC. The selection of cutting tool due to hardness of material to be machined is important. Although CBN can be assigned for all hardness but the cost of this cutting tool is much higher than ceramics and cemented carbide.

The application of hard machining is much in demand by metal cutting industry as a method to produce products, parts, and/or machine components. Therefore, research on perfecting the technology on hard machining is widely studied and reviewed [2,3]. Among the studies to the day, research in hard machining is much under the influence of the advances of coating technology that applied for cutting tool materials, especially for cemented carbide [2]. There are many coating materials have been developed and applied for coating of cutting tools. The famous methods for coating the cutting tools are chemical vapor deposition (CVD) and physical vapor deposition (PVD). The most implemented coating materials and their characteristics are given in Table 1.

Table 1. Most implemented coating materials and their characteristics [4].

| Valuation | Chemical stability | Oxidation stability | Hardness (20°C) | Hot hardness |
|-----------|--------------------|---------------------|-----------------|-------------|
| ++        | Al₂O₃              | Al₂O₃               | TiC             | Al₂O₃       |
| +         | TiAlN              | TiAlN               | TiCN            | TiAlN       |
| 0         | TiN                | TiN                 | Al₂O₃           | TiN         |
| −         | TiCN               | TiCN                | TiAlN           | TiCN        |
| − −       | TiC                | TiC                 | TiN             | TiC         |

2. Hard metals

Hard metals are widely used as raw materials in producing cutting tools for metal cutting. The cutting tool made of hard metals with the WC phase and Co binder is called Cemented Carbides. This cutting tool is remarkable, and as the introduction of coating technology, Coated Cemented Carbide becomes more famous and the first choice for the metal cutting industry [5].

Just after the invention of Cemented Carbides, a TiC-based hard metals called CERamic METal (Cermet) was introduced as a cutting tool. Cermet constitutes of a ceramic matrix bonded by a metallic binder, and the most used system among TiC-based Cermet is TiCxN1-x-Mo-Ni [6,7]. The definition of Cermet was reported in [6] based on the description composed by W. Lengauer. Cermet's ceramic and metal combination upgrades the cutting tool’s properties with the right mix of hardness, wear resistance, and toughness. However, the properties are still lower than Cemented Carbide. In room-temperature, Cermet has an optimum combination of hardness (HV) and fracture toughness (KIC) of (1400-1750 HV30, 7-12 MPa ·√m) when Cemented Carbide of (1100-2000 HV30, 10-24 MPa ·√m) [6]. In contrast, Cermet is better than Cemented Carbides at elevated temperature due to the ceramic matrix's existence as the dominant phase in the Cermet. Since challenging machining operation is generally dried and thus, high cutting temperature, the ceramic matrix presence is beneficial. It is the avenue to promote Cermet as an alternative cutting tool applied for hard machining.

3. Ceramic Metal (Cermet) as Cutting Tool

As mentioned in the latter paragraph, Cermet has low fracture toughness than Cemented Carbide. This handicap was studied by many researchers and the studies to refine or raise the fracture toughness value of Cermet were reported in [8-11]. The refinement method modified the composition chemical and the ceramic phase of microstructure with ultrafine- or nano-Ti(CN) powders and secondary carbide additives. The additives made Cermet conventional with a double structure phase hard, and a step bonded became four phases hard with different compositions and particle sizes (see Figure 1). The fracture toughness could be raised due to the coexistence of the phase hard of a double structure (TiCN-based Cermet), the second challenging phase of a dual system (core W-rich), and a single hard of solid-
solution CN plus fine particles of TiCN were distributed within the binder phase. The TiCN-based Cermet with secondary carbides has a typical core bounded with rim structure. This rim structure supported the core material to gain higher toughness. The body, which was determined with rim structure, governed Cermet's properties, and in this case, the microstructure would be expected to improve Cermet's mechanical properties.

![Microstructure of Cermet](image1.png)

**Figure 1.** Microstructure of Cermet: (a) Conventional with a double structure hard phase and a bonded phase, and (b) Modified (T1500A series) with four hard phases [11].

More studies on Cermet's microstructure to raise its mechanical properties, particularly fracture toughness, had been reported in some journal papers. Kim et al. [12] worked on the effect of complete solid-solution (CSS) of (Ti0.93W0.07) C on Ti(CN)-based partially-complete solid-solution cermet. It was reported that mixing CSS powder with Ti(CN)-based carbide cermet powder would end with remarkable changes in Cermet's overall microstructure. The addition of CSS would improve the microstructure and fracture toughness of TiCN-based Cermet from 8.75 MPa Õm to 11.1 MPa Õm. In another study, Complete solid-solution cermets (CSCs) was enriched with high entropy alloys (HEAs) binder [13]. The flowchart for manufacturing the CSCs using HEAs as the binder phase is presented in Figure 2. The HEAs binder was a solid solution alloy and made of at least 5 (five) combined major metal elements in equivalent atomic percentages [14]. The best result was reported by CoCrFeNiV binder in which hardness and fracture toughness of Cermet resulted at HV50 1048 and K1C 6.8 MPa Õm [13].

Zhou et al. [15] pointed out their work on the sintering process to improve Cermet's mechanical properties. Sintering temperature and holding time were studied during the sintering process of Ti(C0.7, N0.3)Mo Ni-Co (TMNC) and Ti(C0.7, N0.3)WC, TaC, HfC, Mo Ni-Co (TWMNCTH). It was reported that sintering temperature and holding time affected the flexural strength and microstructure, but hardness and fracture toughness were not impacted. The optimum result was observed when a sintering
temperature of 1400°C and a holding time of 30 minutes. The flexural strength, hardness, and fracture toughness were recorded at (1787 ± 132 MPa) (18.75 ± 0.15 GPa) (6.02 ± 0.12 MPa \(\text{m}^{\frac{1}{2}}\)) for TMNC, and at (1563 ± 120 MPa) (19.34 ± 0.15 GPa) (6.09 ± 0.30 MPa \(\text{m}^{\frac{1}{2}}\)) for TWMNCTH.

Cardinal et al. [16] produced 4 (four) green compaction cermet specimens. Those green cermet specimens were first blended for 24 hours, followed by hot pressed in graphite die under argon atmosphere for 1 hour at 1850°C and pressure of 50 MPa. As the final process, those green specimens were dewaxed at 600°C for 1 hour under vacuum and then pressureless sintered under argon atmosphere at 1550°C for 2 hours. The dense materials with specific core/rim structure were obtained. The addition of TiN had positive impact to increase toughness, but it was prone to decrease hardness. The microstructure and mechanical properties of those cermet specimens are as shown in Figure 3 and Table 2, respectively.
Figure 3. Microstructure of specimens: (a) Cermet 1: 0%TiN 20%Ni, (b) Cermet 2: 10%TiN 20%Ni, (c) Cermet 3: 0%TiN 15%Ni, and (d) Cermet 4: 10%TiN 15%Ni [16].

Table 2. Mechanical properties of cermet specimens [16].

| Cermet number | Density (g/cm³) | E (GPa) | H_v0.3 (kg/mm²) | K_1C (MPa √m) |
|---------------|----------------|---------|-----------------|----------------|
| 1             | 5.58           | 400 ± 10| 1360 ± 130      | 13.8 ± 0.7     |
| 2             | 5.56           | 390 ± 9 | 1235 ± 95       | 14.2 ± 0.9     |
| 3             | 5.42           | 410 ± 10| 1520 ± 100      | 10.3 ± 0.5     |
| 4             | 5.41           | 396 ± 10| 1420 ± 115      | 13.6 ± 0.5     |

The study concluded that the specimen with 10 wt% of TiN and 15 wt% of Ni reached an optimum mechanical property which hardness $H_v0.3$ of $(1420 ± 115 \text{ kg/mm}^2)$ and fracture toughness of $(13.6 ± 0.5 \text{ MPa } \sqrt{\text{m}})$ (Cermet number 4 in Table 2). This value was higher than fracture toughness value $(7-12 \text{ MPa } \sqrt{\text{m}})$ of the common TiCN-based Cermet and thus, the specimen could be a good candidate for Cermet cutting tool.

4. Cermet Cutting Tool Applied for Hard Machining

4.1. Uncoated Cermet

Literature study showed that only few research activities on the application of Cermet for hard machining were reported in journal papers. Yang et al. [17] reported the use of Cermet made of $(\text{Ti}_{0.5}, \text{W}_{0.5})\text{C}-15\%\text{wt} \text{ Co}$ and enriched with $(5-20)\%$ of $\text{Mo}_2\text{C}$ as a binder for hard turning of VDEH90CrSi5 steel (62 HRC) at cutting speed of 280 rpm, feed of 0.12 mm/rev, and depth of cut of 0.2 mm. It was resulted that Cermet cutting tool which enriched with 15% and 20% of $\text{Mo}_2\text{C}$ showed better flank wear resistance (see Figure 4). Wear was observed as the integrated results of abrasive, adhesive, oxidative and diffusive wear mechanisms. The addition of $\text{Mo}_2\text{C}$ was effective solution to overcome the wear mechanisms except the oxidative wear. The study was continued with cutting speed of $(180-450) \text{ rpm}$,
feed of (0.8 - 0.20) mm/rev, and depth of cut of (0.2 - 0.5) mm. The study concluded that Cermet cutting tool with 15% of Mo$_2$C was the first choice due its high cutting capability [18].

![Worn cutting tool of Cermet enriched with Mo$_2$C: (a) 0%, (b) 5%, (c) 10%, (d) 15%, and (e) 20% (flank wear of 15% and 20% Mo$_2$C were lesser)](image)

**Figure 4.** Worn cutting tool of Cermet enriched with Mo$_2$C: (a) 0%, (b) 5%, (c) 10%, (d) 15%, and (e) 20% (flank wear of 15% and 20% Mo$_2$C were lesser) [17].

In the study of Chen et al. [19], it was observed that Ti(CN)-based Cermet provided longer tool life than Coated Cemented Carbide (TiCN/Al$_2$O$_3$/TiN) when applied for the hard turning of steel (62 HRC) at cutting speed of 60 and 80 m/min, feed of 0.1 mm/rev, and depth of cut of 0.2 and 0.5 mm (see Figure 5 for the plots). In the case of surface roughness, however, Cermet produced a higher Ra value than Coated Cemented Carbide when cutting at a speed of 60 m/min and depth of cut of 0.2 mm (see Figure 6 for the plots). In this study, the service time of Cermet was terminated by flank wear and crater wear.
Figure 5. Plots of cutting time vs. flank wear for Cermet and Coated Cemented Carbide [19].

Figure 6. Plots of cutting time vs. roughness for Cermet and Coated Cemented Carbide [19].
4.2. Coated Cermet

As Coated Cemented Carbide, Cermet is also coated by some coating materials. It is widely accepted that coating is aimed for better performance of cutting tool. As a coating layer, coating material has two benefits. Firstly, is as an armor suit to reduce tool wear rate and secondly is as a solid lubricant to reduce friction and heat during chip formation. Both are working simultaneously; thus, better tool performance can be provided. Literature study showed that the application of Coated Cermet for hard machining is not as intensive as Coated Cemented Carbide cutting tool [1,2]. Among the journal papers available on the application of Coated Cermet for hard machining, Yang et al. [20] reported the performance of TiCN-based Cermet that coated with TiAlN and TiAlN/CrAlN. Coating layer made of TiAlN and TiAlN/CrAlN deposited on the Cermet substrate are presented in Figure 7. From the figure, it can be observed that the TiAlN coating layer is firmly bonded on the surface of Cermet substrate. In contrast, there is a crack followed at the interface between the TiAlN/CrAlN coating layer and Cermet substrate, as shown in Figure 7(b). The interaction between Al and Cr (Al-Cr) reduces Al's amount to form Al-N phase formation. Since Al-N bond is the primary binding force between coating materials TiAlN/CrAlN and Ti(CN) substrate, the Al-N phase reduction weakens the adhesion between layers substrate and consequently, the crack is occurred. These Coated Cermet cutting tools were used in turning the 9CrSi2Mn steel with hardness of (53-55) HRC. Cutting speed of 280 rpm (44 m/min), feed 0.12 mm/rev, and depth of cut of (0.2, 0.4, and 0.6) mm were assigned. The conclusion that could be taken from the study was that the PVD-coated Cermet with TiAlN coating with a hybrid structure of columnar and block grains showed a better resistance to adhesive failure and flank wear than the TiAlN/CrAIN coating. However, TiAlN suffered from oxidative wear. The benefit of coating materials or layer(s) was proven where the uncoated Cermet cutting tool showed severer wear than the TiAlN and TiAlN/CrAIN Coated Cermet cutting tools. The plots of cutting time versus the evolution of flank wear for that uncoated Cermet (substrate) and both coated Cermet cutting tools are presented in Figure 8.

![Figure 7. Cermet cutting tools: (a) coated with TiAlN, and (b) coated with TiAlN/ CrAlN [20].](image-url)
In the work of Das et al. [21], PVD-coated Cermet (TiN/TiCN/TiN) was applied for turning of EN24 steel with hardness of 48 HRC. Turning was carried out under dry and mist cooled environments at cutting speed of (80, 100, 120) m/min, feed of (0.05, 0.1, 0.15) mm/rev, depth of cut (0.1, 0.2, 0.3) mm. In both cutting environments, flank wear and crater wear were observed as the failure mode of the PVD-coated Cermet. In general, the flank wear and the crater wear were lesser under mist cooled cutting. Surface roughness generated under mist cooled cutting ($0.623 \leq Ra \leq 0.755$) was also better than under dry cutting ($1.20 \leq Ra \leq 2.61$) microns. In another work of Das et al. [22], the activity of turning EN24 steel (48 HRC) was done at cutting speed of (150, 200, 250) m/min, feed of (0.09, 0.17, 0.25) mm/rev, depth of cut (0.4, 0.6, 0.8) mm by using a PVD-coated Cermet Ti(C,N,O). Flank wear was also observed as the dominant tool failure mode. The flank wear width (VB) was reported ranging between (0.221-0.77) mm while for surface roughness, Ra was recorded ranging between (1.065-4.011) microns. A footnote should be taken to this study. The flank wear width (VB) value of 0.77 mm is a strong indicator of excessive flank wear to promote a catastrophic (brittle fracture) at the tool cutting edge. However, this detail was not reported.

Although hard machining is commonly categorized for processing ferrous steel with minimum hardness of 45 HRC, but to take the benefit of information for Coated Cermet, the work of Ji et al. [23] is included in this review. They designed and fabricated a Gradient Cermet Composite. The outer surface of the cermet had a high hardness and the subsurface layer possessed a high bonding strength while the substrate exhibited a high flexural strength (Figure 9). The cutting tool was assigned for turning of 17-4PH stainless steel with hardness of 43 HRC at cutting speed of 150 m/min, feed 0.1 mm/rev, and depth

**Figure 8.** Plots of cutting time vs. flank wear at depth of cut: (a) 0.2, (b) 0.4, and (c) 0.6 mm [20].
of cut 0.3 mm. It was recorded that the cutting tool could be used for 89 minutes (tool life) to reach flank wear (VB) of 0.3 mm. Surface roughness was recorded at (1.0-1.5) microns. The performance of Gradient Cermet Composite was almost two folds of the ordinary TiCN Cermet cutting tool with tool life of 49 minutes when assigned at the same cutting condition.

Figure 9. Gradient Cermet Composite: formation process models (a. before sintering, b. during sintering, c. after sintering), and SEM images (d. macro morphology, e. microstructure) [23].

Using multilayer (TiN/TiCN/TiN) Coated Cermet, Tiwari et al. [24] turned AISI 4340 steel with hardness of 56 HRC. The Coated Cermet (TiN/TiCN/TiN) was assigned at cutting conditions of cutting speed of (70-210) m/min, feed of (0.05-0.2) mm/rev, depth of cut (0.1-0.5) mm. The study showed that surface roughness generated under those cutting conditions was ranging between (0.212 ≤ Ra ≤ 1.452) microns. Since the values of surface roughness were recorded less than finish turning standard criterion (Ra ≤ 1.6 microns), it was safe to conclude that the Coated Cermet could be applied for finish turning of hardened steel.

Cermet cutting tool made of substrate of Ti(C, N)-12Mo2C-6TaC-6WC-9Ni-9Co was coated under CVD technique with four layers, i.e. TiN, MT-TiCN, α-Al2O3, TiN (from the inner to the outer surface and total thickness about 12 microns) [25]. The CVD-coated Cermet then was tested in turning of hardened AISI H13 steel with hardness of 50 HRC. Cutting conditions were selected at cutting speed of (300, 500, 700) rpm, feed of (0.2, 0.4, 0.6) mm/rev, and depth of cut of (0.05, 0.07, 0.09) mm. Testing was carried out until flank wear width (VB) of 0.3 mm reached. The work showed that the CVD-coated Cermet provided the longest tool life when turning at cutting speed ≥ 700 rpm, feed 0.05 mm/rev, and depth of cut 0.2 mm, and a good surface quality of machined surface generated. The CVD-coated Cermet showed an excellent wear resistance to diffusion and adhesion at elevated temperature.

4.3. Machinability Aspects and Productivity

In section 3, the machinability aspects were related to the performance of Cermet cutting tool. Tool wear, tool life, and surface roughness as part of machinability aspects were reported. As hard machining technology is aimed to give significant savings in cost and increase in productivity [1]; thus, besides characterizing the performance of Cermet through machinability aspects, it is also urgent to study the characteristic of Cermet performance in term of productivity.

In metal cutting, material removal rate (MRR) is a most important economical aspect to evaluate the productivity of cutting process [26]. Mathematically, MRR can be given as:

\[ MRR = v \cdot f \cdot a \]  

where:  
MRR (cm³/min),  
cutting speed (v) (m/min),  
feed (f) (mm/rev), and  
depth of cut (a) (mm)
It has been shown in section 3, cutting parameter (v, f, a) or their combination as cutting condition rules the tool performance (tool wear, tool life, surface roughness). As MRR is also controlled by cutting condition (see Equation 1), MRR has a close relationship with tool performance. In this sense, MRR can be concluded in the form of:

\[ \text{MRR} = \phi (v, f, a, \text{tool wear, tool life, surface roughness}) \]  

(2)

Equation (2) shows that MRR is depending not only on cutting condition but also on tool performance. Based on the aspects enveloped in Equation (2), Ginting et al. [27, 28] introduced a new parameter to represent the productivity in metal cutting which is called volume of material removal (VMR). VMR can be defined as the amount of chip that produced by a cutting edge when a cutting tool that is assigned for cutting under a certain cutting condition reach its tool life criteria. In metal cutting tool life criteria are commonly determined by tool wear and surface roughness. VMR is in unit of (cm$^3$/cutting edge) and mathematically can be given as:

\[ \text{VMR} = \text{MRR} \cdot \text{tool life} = (v \cdot f \cdot a) \cdot T \]  

(3)

Sarjana et al. [29] adopt the VMR parameter (with Q notation in Table 3) to calculate the productivity using Equation (3) for some Cermet cutting tools when applied in hard machining. The summary of calculation reported is given in Table 3. From Table 3, besides productivity given by a Cermet cutting tool in row number 24 (88 cm$^3$/cutting edge), the productivity provided by the Cermet cutting tools studied by Sarjana et al. [29] (row number 1 (81.60 cm$^3$/cutting edge) and row number 2 (43.20 cm$^3$/cutting edge)) showed a good potency to be applied in hard turning of ferrous alloy AISI 4340 with hardness of 50 HRC with acceptable limit of tool wear (VB) and a good quality of finish turning in term of surface roughness (Ra). The Uncoated Cermet (row number 1) produces higher productivity but better surface finish is generated by the Coated Cermet (row number 2).

**Table 3. Summary of performance of Cermet in term of productivity (VMR or Q) [29].**

| No | Cermet cutting tool | Cutting condition | MRR | VB | Ra | T | Q | Mat. Hard | Ref. |
|----|---------------------|-------------------|-----|----|----|---|---|-----------|------|
| 1  | Uncoated Ti(C,N)-based | 120.00 0.10 0.2 | 2.40 125 1.773 | 34.0 81.60 50 | PS* |
| 2  | + PVD-Coated         | 120.00 0.10 0.2 | 2.40 100 0.891 | 18.0 43.20 50 |
| 3  | Uncoated (Ti0.5,W0.5)C  | 43.98 0.12 0.2 | 1.06 300 N/A 6.0 | 6.33 62 |
| 4  | 3 + 5 wt% Mo2C       | 43.98 0.12 0.2 | 1.06 300 N/A 7.0 | 7.39 62 |
| 5  | 3 + 10 wt% Mo2C      | 43.98 0.12 0.2 | 1.06 300 N/A 13.0 | 13.72 62 |
| 6  | 3 + 15 wt% Mo2C      | 43.98 0.12 0.2 | 1.06 300 N/A 20.0 | 21.11 62 |
| 7  | 3 + 20 wt% Mo2C      | 43.98 0.12 0.2 | 1.06 300 N/A 21.0 | 22.17 62 |
| 8  | Uncoated (Ti0.5,W0.5)C  | 43.98 0.12 0.2 | 1.06 300 N/A 6.0 | 6.33 62 |
| 9  | 8 + 10 wt% Mo2C      | 43.98 0.12 0.2 | 1.06 300 N/A 13.0 | 13.72 62 |
| 10 | 8 + 15 wt% Mo2C      | 43.98 0.12 0.2 | 1.06 300 N/A 20.0 | 21.11 62 |
| 11 | 8 + 15 wt% Mo2C      | 28.27 0.12 0.2 | 0.68 300 N/A 32.0 | 21.71 62 |
| 12 | 8 + 15 wt% Mo2C      | 34.56 0.12 0.2 | 0.83 300 N/A 25.0 | 20.73 62 |
| 13 | 8 + 15 wt% Mo2C      | 70.69 0.12 0.2 | 1.70 300 N/A 9.0 | 15.27 62 |
| 14 | 8 + 15 wt% Mo2C      | 43.98 0.08 0.2 | 0.70 300 N/A 23.0 | 16.19 62 |
| 15 | 8 + 15 wt% Mo2C      | 43.98 0.16 0.2 | 1.41 300 N/A 17.0 | 23.93 62 |
| 16 | 8 + 15 wt% Mo2C      | 43.98 0.20 0.2 | 1.76 300 N/A 18.0 | 31.67 62 |
| 17 | 8 + 15 wt% Mo2C      | 43.98 0.24 0.2 | 2.11 300 N/A 19.0 | 40.11 62 |
| 18 | 8 + 15 wt% Mo2C      | 43.98 0.24 0.3 | 3.17 300 N/A 13.0 | 41.17 62 |
| 19 | 8 + 15 wt% Mo2C      | 43.98 0.24 0.4 | 4.22 300 N/A 9.0 | 38.00 62 |
| 20 | 8 + 15 wt% Mo2C      | 43.98 0.24 0.5 | 5.28 300 N/A 6.0 | 31.67 62 |
| 21 | Uncoated Ti(C,N)-based | 60 0.10 0.2 | 1.20 300 1.90 | 61.0 73.20 63 | [23] |
| 22 | Uncoated Ti(C,N)-based | 60 0.10 0.5 | 3.00 300 N/A 39.0 | 117.00 64 |
| 23 | Uncoated Ti(C,N)-based | 60 0.10 0.2 | 1.60 300 N/A 44.0 | 70.40 65 |
| 24 | Uncoated Ti(C,N)-based | 60 0.10 0.5 | 4.00 300 N/A 22.0 | 88.00 66 |
| 25 | Uncoated Ti(C,N)Ni-10 wt%Mo2C | 43.98 0.12 0.2 | 1.06 300 N/A 10.00 10.56 (53-55) | [24] |
Summary and Outlook

PVD coated Ti(C,N)N1-10 wt%Mo2C

| Coating Type | Hardness (GPa) | Fracture Toughness (MPa.m^0.5) |
|--------------|---------------|-------------------------------|
| Uncoated Ti(C,N)N1-10 wt%Mo2C | 43.98 | 0.12 |
| 27 + PVD-Coated (TiAlN) | 43.98 | 0.12 |
| 27 + PVD-Coated (TiAIN) | 43.98 | 0.12 |
| 27 + PVD-Coated (TiAIN/Coated) | 43.98 | 0.12 |
| PVD-Coated (TiAIN/Coated) | 43.98 | 0.12 |

Note: [21] to [26] in this table were references in Sarjana et al. [29]

5. Summary and Outlook

Besides WC-Co hard metals or well known as Cemented Carbide, the TiC-based hard metals has been proposed as a cutting tool in the field of metal cutting. This cutting tool is called Ceramic Metal (Cermet). Cemented Carbide is widely used due to a very successful combination of hardness and toughness; however, the TiC-based Cermet has not found extended use due to its brittleness or low fracture toughness. The improvement of fracture toughness for TiC-based Cermet finds its way when
titanium nitride (TiN) is introduced as an additive constituent. The addition of TiN to the conventional TiC-based Cermet produces a TiCN-based modern Cermet which is characterized microstructurally by a structured hard phase featuring core-rim structures embedded in a tough Co-Ni binder. The improvement is also studied through modifying the binder by high entropy alloys binder technique and the sintering process (sintering temperature and holding time) of green body. Cermet is better than Cemented Carbides at elevated temperature due to the existence of ceramic matrix as the dominant phase in the Cermet. Since hard machining operation is generally dried and thus, cutting at high temperature; the existence of ceramic matrix is beneficial. This benefit plus improved fracture toughness is the avenue to promote TiCN-based Cermet as an alternative cutting tool applied for hard machining.

As an insert type cutting tool, Cermet is available uncoated and coated. When applied for hard turning of hardened steel, both cutting tools can effectively and economically be used at cutting conditions of finish operation. Longer tool life can be produced at low cutting speed, feed, and depth of cut. In the case of surface finish, the coated Cermet generates better surface roughness than the uncoated. Surface finish even better when hard turning is carried under mist cooled environment rather than dried. Flank wear, crater wear are the failure modes of both Cermet cutting tools. Higher cutting speed tends to promote the excessive flank wear, chipping, and brittle fracture. Tool wear is caused by several wear mechanisms that can be occurred simultaneously such as abrasive, adhesive oxidative, and diffusive wear mechanisms.

Hard machining technology is prepared to increase a productivity in metal cutting. Instead of material removal rate (MRR), another parameter called volume of material removal (VMR) has been introduced to represent productivity. The results of calculation on VMR show that both uncoated and coated Cermet cutting tools are potential to increase productivity in hard turning of ferrous alloys. The Uncoated Cermet produces higher productivity, but better surface finish is generated by Coated.

In order to gain a maximum benefit from Cermet cutting tool applied for hard machining of ferrous alloys, some potential research topics for future works are recommended and written. On the aspect of substrate, study on design of substrate metallurgy by using of nano-TiCN powders plus the other additional elements such as Mo2C which enriched with high entropy alloys binder is potential to produce the green body of Uncoated Cermet. It is then followed by study on the sintering process of the green body by means finding the optimum condition of temperature and holding time under the sintering atmosphere.

On the aspect of coating layer, the adhesive force between substrate and coating layer is urgent to be studied. It is to ensure that the interface between substrate and coating layer is strongly and evenly bonded in order to avoid any crack. The chemical reaction between substrate and coating materials during coating process are concerned. The enrichment of Gradient Cermet Composite with coating layer(s) is also promising. Moreover, the information on the rule of thumb related to the performance of single and multilayer of Coated Cermet applied for hard machining can also be studied.

On the aspect of cutting technique, it is expected that the existence of coating layer on Coated Cermet is not only for better surface finish (coating material as a solid lubricant) but also for prolonging tool life (coating material as a solid coolant). However, Coated Cermet tends to provide only better surface finish while better VMR (MRR and tool life) is provided by the Uncoated Cermet. Although expectation to have a tough Coated Cermet is produced through the study of coating layer aspect, but the cutting technique such as mist cooled or minimum quantity lubricant (MQL) technique which enriched by study on the type of cutting fluids is also potential to increase the performance of Coated Cermet.

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