Cutting Characteristics of Coated Carbide Tools in Hardmilling

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Abstract:
The cutting performance of coated carbide tools in hardmilling is investigated. Four kinds of coating films: TiN, TiCN, TiAIN and multi-layered TiAIN/AlCrN: are coated on two types of carbide materials: JIS K20 and P30. The tool flank wear $VB$ depends considerably on the hardness and oxidizing temperature of coating film. In the case of TiN, TiCN and TiAIN, the tool flank temperature $\theta_a$ rises with cutting, but it does not increase in TiAIN/AlCrN. When the base material is K20, $\theta_a$ is lower than that of P30 because of high thermal conductivity. The tool temperature and tool wear has great influence on the surface roughness of workpiece.

Keywords: Coated tool, Hardmilling, Tool wear, Tool temperature, Two-color pyrometer

1. Introduction
Difficult-to-machining materials such as hardened steel and/or high speed steel are widely used in dies and molds. In manufacturing process of dies, these steels should be machined to a certain 3D form. The hardened steel, however, leads to the increase of cutting force and cutting temperature. In particular, the cutting temperature promotes tool wear and tool fracture. Therefore, thermostability of the tool material is the most important characteristics in cutting such hardened steels. Several researches have been conducted on the temperature of the cutting tool, with the purpose of improving cutting of high hardness steels. Ueda et al. [1] measured the temperature at the tool flank face using a two-color pyrometer with a fused fiber coupler and investigated the influence of cutting speed on the temperature of a cBN tool in hard turning.

In end milling, the cutting tool is not in constant operation and so undergoes a heat cycle during the intermittent cutting. The heat cycle is one of the main causes of tool failure because of wear or fracture. It is, however, difficult to measure the temperature of an end milling tool correctly because the cutting tool rotates at high speed and the area to be measured is very small. The authors succeeded the temperature measurement of the cBN tool in high-speed hardmilling [2].

In this study, the cutting performance of coated carbide tools in low-speed hardmilling is investigated. The cutting characteristics are evaluated by tool wear, cutting temperature at the flank face, cutting force and surface roughness. The temperature of cutting tool is measured using a two-color pyrometer with an optical fiber. The influences of cutting length on the tool flank wear, tool flank temperature and cutting force are examined with four kinds of coating films that coated on two types of carbide materials.

2. Experimental method

2.1 Two-color pyrometer
The schematic illustration of the two-color pyrometer is shown in Fig.1. The infrared rays radiated from the cutting tool are accepted by a chalcogenide glass fiber and led to the two-color detector in corporate an InAs photodetector mounted over an InSb detector along the same optical axis. The InAs detector responds to incident radiation from 1.0µm to 3.0µm and transmits waves larger than 3.0µm, while the InSb detector responds to radiation from 3.0µm to 5.5µm. The infrared energy is converted to an electric signal, and amplified. Taking the ratio of these two detectors, we can calculate the temperature of the object using the calibration curve which is obtained by sighting on a radiating surface of known uniform temperature. Figure 2 demonstrates the calibration curve of the TiAIN specimen and a similar curve is obtained for any target because the sensitivity of the pyrometer is almost independent of emissivity of the object.
2.2 Temperature measurement

A schematic illustration of the experimental arrangement is shown in Fig. 3. The temperature on the flank face when cutting is in progress is measured. The cutting edge is in contact with the workpiece, in which a φ1.1 mm-hole has been made which extends to the tool-workpiece contact area. An optical fiber is inserted into the fine hole from the outer surface and is fixed at the point where the distance between the surface of workpiece to be machined and the incidence face is 0.5 mm. The optical fiber can accept the infrared energy radiated from the flank face of the cutting tool when it passes above the hole.

2.3 Experimental procedure

Dry side milling tests are carried out using a vertical machining center as a milling machine. As work material, a full-hardened carbon steel JIS S55C that is regulated hardness 60HRC by the high-frequency hardening is used. Four kinds of coating films: TiN, TiCN, TiAIN and multi-layered TiAIN/AiCrN: coated on two types of carbide materials: JIS K20 and JIS P30: are chosen as teeth. The SEM image and schematic illustration of the cutting edge is shown in Fig. 4. In this experiment, only one of the teeth is used in cutting in order to avoid the radius difference between the two teeth and to maintain constant cutting conditions. The other tooth is fixed to make a weight balance in rotation. Three components of cutting force are measured by the piezoelectric dynamometer on which the workpiece is mounted. The experimental conditions and physical properties of coating films and base materials are summarized in Table 1, Table 2 and Table 3.

3. Experimental results and discussion

3.1 Tool flank wear

The effect of coating film coated on K20 on the tool flank wear is shown in Fig. 5. Here, cutting length $L_c$ is the actual length calculated from tool-work contact length and number of cutting passes. As is obvious from the figure, the minimum tool wear of $VB=20\mu m$ at $L_c=112m$ is obtained in TiAIN/AiCrN coated tool, and $VB$ increases in order of TiAIN, TiCN and TiN coated tool. The wear resistance depends considerably on the hardness and oxidizing temperature of coating film. As shown in Table 2, the TiAIN/AiCrN coating has the highest hardness and oxidizing temperature and the TiAIN coating has the similar characteristics. Additionally, Yamada et al. [3] reported that aluminum in the coating films is oxidized selectively under the high temperature condition and forms a thin layer of amorphous aluminum oxide, which protects the coating from further oxidation. According to the above consideration, TiAIN and TiAIN/AiCrN offer superior performance for relatively low speed hardmilling from a view of wear resistance.
The SEM image of the cutting edge of TiAIN/AlCrN coated tool of $VB=20\mu m$ at $L_e=112m$ is shown in Fig.6, where structure of the base material is also shown at the same magnification. By comparing both images, it is said that the coating film on the flank face in the vicinity of cutting edge is ablated but the coating film at the boundary edge endures an attach from the tool.

### 3.2 Tool flank temperature

**Figure 7** shows the influence of cutting length on the tool flank temperature. It is clear that the temperature on the flank face $\theta_o$ increases with the increase in cutting length in except for the case of TiAIN/AlCrN coated tool. For instance, $\theta_o$ is about $425\degree C$ at $L_e=1.12m$ and increases to $525\degree C$ at $L_e=112m$ with TiN coated tool. Pay attention to the degree of temperature rise from $L_e=1.12m$ to $L_e=112m$, the TiN coating is the largest and the second is TiCN coating. This tendency seems to be analogous to the increase of tool wear shown in Fig.5.

As for the initial tool temperature when a tool is not worn, the TiCN coated tool is the lowest with approximately $400\degree C$ whereas the TiAIN/AlCrN coated tool is $500\degree C$. This phenomena seems to be expressed by the thermal characteristics of the coating materials although the accurate values are not clear. In general, it is said that the thermal conductivity of TiAIN is approximately 30% smaller than that of TiN, and it can express the results of Fig.7.

In addition, the $\theta_o$ of TiCN coated tool at $L_e=100.8m$ reaches approximately $500\degree C$ which is nearly the oxidizing temperature of TiCN coating film. This is the reason why the $VB$ of TiCN coated tool is larger than that of TiAIN in spite of the fact that TiCN is harder than TiAIN.

### 3.3 Cutting force

The influence of the cutting length on the cutting force (feed force: $F_x$) is shown in Fig.8. The cutting force increases with the increase in cutting length in any tool, and the tendency is the same as the case of the tool flank wear. A large difference, however, is not admitted by the cutting force at $L_e=1.12m$. Consequently, cutting force is greatly influenced in the tool wear, but is not influenced in the coating film material.

### 3.4 Influence of base material on cutting characteristics

The influence of base material of TiAIN-coated inserts on the tool wear is investigated. **Figure 9** shows the changes of tool flank wear with cutting length for two types of base materials: JIS-K20 and P30. It is clear that the wear rate of both tools are almost the same when the cutting length is $56.0m$ or less, but the wear of the P30-based tool increases rapidly as cutting proceeds. The $VB$ of P30-based tool at $L_e=67.2m$ is approximately $25\mu m$, and the base material is exposed at this wear-land. In such a situation, the influence of the base material becomes predominant rather than coating films on the promotion of tool wear. One of the reasons of higher
wear rate of the P30-based tool is due to the thermal characteristics of the base material. As shown in Table 3, the thermal conductivity of P30 is considerably small compared to K20, so that the cutting temperature of P30-based tool rises more than K20-based tool, which leads to the higher wear rate. This explanation may be verified by the cutting results with cBN tools having different thermal conductivities [4]. In addition, the wear resistance of K20-carbides seems to be more excellent under the intermitted cutting of hardened steels.

3.5 Surface roughness of workpiece

The relationship between cutting length and arithmetic surface roughness $R_a$ of workpiece for three types of coated tool is shown in Fig.10. The surface roughness decreases to a minimum value at a certain cutting length and then increases as cutting proceeds. This phenomena seems to be expressed by tool temperature and tool wear. Figure 11 represents the surface roughness as a function of tool flank temperature. From the figure, it is found that the surface roughness becomes minimum when the tool temperature is around 500°C~525°C, which is a little higher than the recrystallizing temperature of steels. It can be therefore explained that the decrease of surface roughness with the increase in $\theta_a$ is due to the reduction and/or disappearance of the adhesion of work material to the cutting edge. On the other hand, the deterioration of the surface roughness at higher tool temperature seems to be caused by the change of cutting-edge geometry of worn tool.

4. Conclusions

The cutting characteristic of coated carbide tools in hardmilling is investigated. In dry cutting of hardened carbon steel with the four kinds of coating films: TiN, TiCN, TiAIN and multi-layered TiAIN/AlCrN; coated on K20, the TiAIN/AlCrN which has the highest hardness and oxidizing temperature is obtained highest wear resistance, and the tool flank face $VB$ is approximately 20μm at $L_c$=112m in cutting length. The tool flank temperature $\theta_a$ reaches approximately 500°C with TiAIN/AlCrN coated tool and it does not rise so much with cutting. In the case of TiCN coated tool, however, $\theta_a$ is lower by 80°C or more than TiAIN/AlCrN coated insert but it increases with cutting and reaches approximately 500°C at $L_c$=112m. When the base material is K20, $VB$ is lower than that of P30 about 50μm at $L_c$=112m for TiAIN coated tool. The surface roughness of workpiece decreases to a minimum value at a certain cutting length and then increases. The multi-layered TiAIN/AlCrN coated tool that has the highest hardness and oxidizing temperature is most available in milling of hardened steel at low cutting speed.

Acknowledgement

The authors are indebted to Mori Seiki Co., Ltd. and Sumitomo Electric Hardmetal Corp. for their support in this research.

References


