Improvement of Cutting Tool Life by AlN Deposition on the Tool

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SCM415 steel was machined with carbide tools in as hot rolled condition and after normalizing heat treatment. In the as-rolled sample, a significant amount of Al and N existed as solid solution; whereas, in the normalized sample, Al and N existed as AlN precipitates. Reduction of tool wear for the as-rolled sample was observed. On the rake face of the tool machined for the as-rolled sample, the presence of AlN deposit was observed. It is believed that Al and N in solid solution form AlN deposit on the tool face due to temperature rise during machining, and that the deposition of the AlN layer on the tool face prevents diffusion between the tool and chip and reduces tool wear.

KEY WORDS: free-machining steel; AlN; machinability; tool life.

1. Introduction

It is known that carbide cutting tool life is improved when machining is carried out with steels deoxidized with Ca.^{1–3)} Protecting layer of oxides and sulfides, so called “belag” is formed on tool face to protect tools from wear. It has been reported that protective layer is not limited to belag of oxides and sulfides, but nitrides can also form protective layer. The first nitride deposit reported to form protective layer was boron–nitride or BN.^{4–6)} Next, deposition of AlN on the tool was reported to form for the samples containing BN.^{7–11)} Further, it was recently reported that the deposition of AlN can take place with the steels even without BN addition.^{11,12)} The deposition of VN can also be formed.¹³⁾

These observations suggest a possibility of a new type of free-machining steel. Thus, investigation was initiated to clarify the condition of AlN deposition. It is assumed that, if Al and N exist as solid solution in steel, AlN deposit could be formed on the cutting tool during machining due to temperature rise.

2. Experimental Procedure

Industrially made Al-killed JIS SCM415 steel was selected, and hot rolled to 60 mm diameter bar in the industrial bar rolling mill. The chemical composition was 0.17% C, 0.19% Si, 0.72% Mn, 0.016% S, 1.05% Cr, 0.23% Mo, 0.024% Al, 0.0106% N. No special de-oxidation practice was utilized. The as-rolled sample and the sample normalized at 900°C×2 h after rolling were investigated. It is expected that, in the as-rolled sample a significant amount of Al and N exist as solid solution, and in the normalized sample, most of Al and N exist as AlN precipitates and the amount of Al and N in solid solution is small. According to

equilibrium thermodynamic calculation, at 900°C, approximately 80% of Al is combined as AlN.

Turning experiments with P10 carbide tools was carried out as machining test under dry condition, with cutting speed of 200 m/min, feed of 0.25 mm/rev and depth of cut 1.5 mm. Tool wear on both rake face and flank face was measured at certain machining periods

3. Results and Discussion

Figure 1 shows typical microstructure of the as-rolled and normalized samples. The as-rolled sample has ferrite–bainite microstructure and hardness of HV166. The normalized sample has ferrite–pearlite microstructure and hardness of HV138. **Figure 2** shows a typical oxide inclusion observed. Oxides are Al₂O₃ or spinel type containing Mg which is believed to come from refractory. Sulfide inclusions were the typical elongated type.

Figures 3 and **4** show crater wear and flank wear measurement results, respectively. Significant reduction of crater wear for the as-rolled sample is observed in spite of higher hardness. Flank wear for the as-rolled sample is also small.

Figures 5 and **6** show X-ray mapping in EPMA on crater tool faces for the as-rolled and normalized samples. For the as-rolled sample (**Fig. 5**), Al and N are clearly detected on the same area of worn tool face. On the other hand, the presence of belag or deposit of oxides and sulfides is not observed on the worn area. **Figure 7** shows small size X-ray diffraction analysis on the area where both Al and N are observed. The presence of AlN is suggested. Arrows on the top of the figure indicate the peaks of AlN. As shown in **Fig. 6**, weak Al and N are also observed for the normalized sample. However, as shown in **Fig. 8**, the presence of AlN is not confirmed for the normalized sample by X-ray dif-

Fig. 1. Microstructure of the samples.

Fig. 2. Typical Al_2O_3 type oxide inclusion observed.

Fig. 3. Crater wear measurement results.

Fig. 4. Flank wear measurement results.

fraction.

In order to investigate the origin of AlN deposit on the tool, chemical analysis was carried out to measure not only total Al and N but also Al and N in solid solution. Al and N in solid solution were analyzed by the following method. The details of analyzing method are summarized in **Table 1**.

$$\text{Al (solution)} = \text{Al (total)} - \text{Al as } \text{Al}_2\text{O}_3 - \text{Al as } \text{AlN}$$

$$\text{N (solution)} = \text{N (total)} - \text{N (combined)}$$

Table 2 shows the analyzed results of Al and N in solid solution. It is clearly shown that the as-rolled sample, which had smaller tool wear contains higher amount of Al and N in solid solution. This clarifies that Al and N were dissolved during hot rolling. During following normalizing heat treatment, Al and N in solid solution were combined to AlN as suggested by thermo-dynamical estimation.

Due to heavy and rapid deformation during machining, significant localized heat generation takes place. It has been reported that the maximum temperature in the tool-chip in-

Fig. 5. X-ray mapping in the EPMA of the rake face of the tool used for the as-rolled sample.

Fig. 6. X-ray mapping in the EPMA of the rake face of the tool used for the normalized sample.

terface reaches 1 000°C or higher for the cutting conditions similar to the condition used in this investigation.^{14,15)} Thus, it is reasonable to believe that the soluble Al and N in the steel combine at the tool-chip interface as AlN due to temperature rise and deposit on the tool surface. Since it has been reported that the presence of AlN layer prohibits diffusion between tool and chip,¹⁰⁾ tool wear is reduced by the presence of AlN deposited layer.

4. Conclusions

Low carbon low alloy steel (SCM415) was machined with carbide tools in as hot rolled condition and after nor-

malizing heat treatment. The following conclusions are obtained:

- (1) The as-hot rolled sample, which contains significant amount of Al and N as solid solution showed smaller tool wear compared with the normalized sample, in which Al and N existed as AlN precipitates.
- (2) On the rake face of the tool machined for the as-rolled sample, presence of AlN was observed. It is believed that Al and N in solid solution form AlN deposit on the tool face due to temperature rise during machining.
- (3) It is suggested that the deposition of the AlN layer on the tool face prevents diffusion between the tool and chip and reduces tool wear.

Fig. 7. X-ray diffraction analysis on the rake face of the tool used for the as-rolled sample. The X-ray was Cu-K α , and the beam size 50 μ m.

Fig. 8. X-ray diffraction analysis on the rake face of the tool used for the normalized sample. The X-ray was Cu-K α , and the beam size 50 μ m.

Table 1. Method to analyze Al and N in solid solution.

$$\text{Al(solid)} = \text{Al (total)} - \text{Al as Al}_2\text{O}_3 - \text{Al as AlN}$$

$$\text{N(solid)} = \text{N(total)} - \text{N(combined)}$$

Analysis	Method
Al(total)	ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy)
Al ₂ O ₃	10%Bromine —methanol extraction → ICP-AES
AlN	Bromine-methyl acetate extraction → Distillation separation titrimetry
N(total)	Inert gas fusion thermal conductivity method
N(combined)	Electrolytic extraction → Colorimetry Solution : 10%Acetylacetone — 1%Tetramethylammonium chloride — methanol

Table 2. Analyzed Al and N in solid solution (mass%).

Sample	Al(total)	Al ₂ O ₃	AlN	Al(solid)	N(total)	N(combined)	N(solid)
As-rolled	0.023	0.0042	0.0017	0.020	0.011	0.0017	0.0093
Normalized	0.023	0.0076	0.021	0.005	0.011	0.0077	0.0033

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