Cutting-Edge Carbide Tools for Aircraft Industry

Sachiko KOIKE*, Kensei HAMAKI, Takato YAMANISHI, and Keiichi TSUDA

In recent years, increased demand in the aircraft market has led to the need for higher production efficiency of aircraft parts. Heat-resistant alloys and titanium alloys, widely employed for aircraft engines and structural members, are classified as difficult-to-machine materials and require cutting tools with high efficiency and long service life. In order to meet these user needs, Sumitomo Electric Industries, Ltd. has developed next-generation cemented carbide tools specialized in machining heat-resistant alloys and titanium alloys. For heat-resistant alloys, a new cemented carbide material with excellent high-temperature properties suppresses plastic deformation and wear even in high-speed, high-feed machining, enabling highly efficient machining. For titanium alloys, a newly developed film coating significantly reduces the reaction with titanium alloys, suppressing adhesion to the tool and extending the service life.

Keywords: heat-resistant alloy, titanium alloy, cutting tool

1. Introduction

The aircraft market is expected to continue to expand in the coming years. In particular, the demand for commercial aircraft is expected to double over the next 20 years by growing at a yearly rate of nearly 4%. To meet such a rapid increase in demand, aircraft and engine manufacturers are accelerating the improvement of component manufacturing efficiency and cost.

The performance of cutting tools plays a very important role in the manufacture of aircraft parts since many of them are finished by machining large size materials. Among these materials, heat-resistant alloys*1 and titanium alloys*2 used for aircraft engines and structural members are classified as difficult-to-machine materials. Since the cost of machining these alloys accounts for a high percentage of the manufacturing cost, the cutting tools are strongly required to be highly efficient and have a long service life.

In order to meet the above market needs, Sumitomo Electric Industries, Ltd. has been promoting R&D of tool materials dedicated for use in the aircraft industry. This paper describes state-of-the-art cemented carbide tool materials dedicated for use for machining heat-resistant alloys and titanium alloys.

2. State-of-the-Art Cemented Carbide Tool for Machining Heat-Resistant Alloys

2-1 Challenges in machining heat-resistant alloys

INCONEL 718, WASPALOY, and other nickel-based heat-resistant alloys are mainly used as materials for the parts to be installed between the combustion chamber and exhaust port of aircraft engines. Figure 1 shows a photo of the typical damage of a cemented carbide tool that was used for machining a heat-resistant alloy. Heat-resistant alloys have low thermal conductivity and high strength. Because of these properties, cutting tools generate heat when machining these alloys. As a result, the tools are worn rapidly and the cutting edges are deformed plastically. It is known that, under normal machining conditions, the cutting edge of the tool is exposed to a high temperature of 700°C or more. Cobalt, which is widely used as the binder*3 of cemented carbide, reduces its hardness as its temperature increases. More specifically, when heated to 700°C, cobalt reduces its hardness to approximately 20% of the value at room temperature, as shown in Fig. 2.(1) This is the cause of the plastic deformation of the cutting edge described above. With the aim of overcoming the above shortcoming of the cutting tool material, we have developed heat-resistant binder cemented carbide having excellent high-temperature properties that are very much suited to heat-resistant alloy machining.

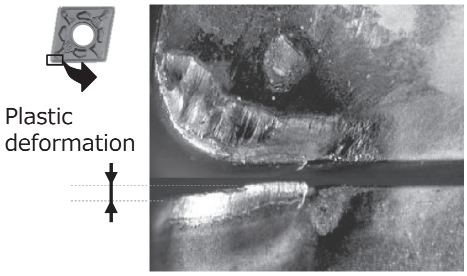


Fig. 1. Tool damage in heat-resistant alloy machining

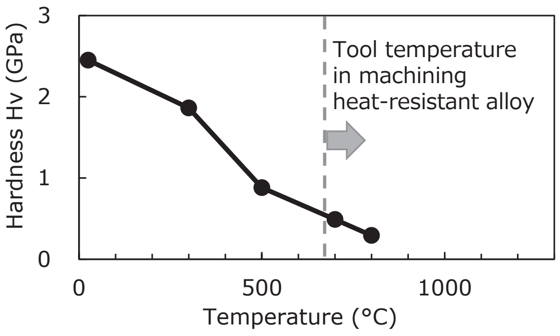


Fig. 2. Relationship between the temperature and hardness of cobalt

2-2 Features of heat-resistant binder cemented carbide

Figure 3 shows the high-temperature compression test results for conventional cemented carbide and heat-resistant binder cemented carbide. The compressive strain of heat-resistant binder cemented carbide at 1,000°C was less than one-fourth that of conventional cemented carbide, indicating that heat-resistant binder cemented carbide is rarely deformed even in a high-temperature environment. Figure 4 shows tool damage and the cross-sectional images of the damaged tools after being used for turning a heat-resistant alloy. The above figure shows that conventional cemented carbide underwent large plastic deformation and the film peeled off the flank, while heat-resistant binder cemented carbide experienced little plastic deformation and small wear. It was confirmed from the above results that heat-resistant binder cemented carbide has excellent resistance to plastic deformation and wear in a high-temperature environment.

2-3 Performance of heat-resistant binder cemented carbide

Figure 5 shows the v-t and f-t diagrams*[4] in the turning of a heat-resistant alloy. As expected from the high-temperature compression test results described in the previous section, it was confirmed that heat-resistant binder cemented carbide provides cutting tools with an excellent service life compared with conventional cemented carbide

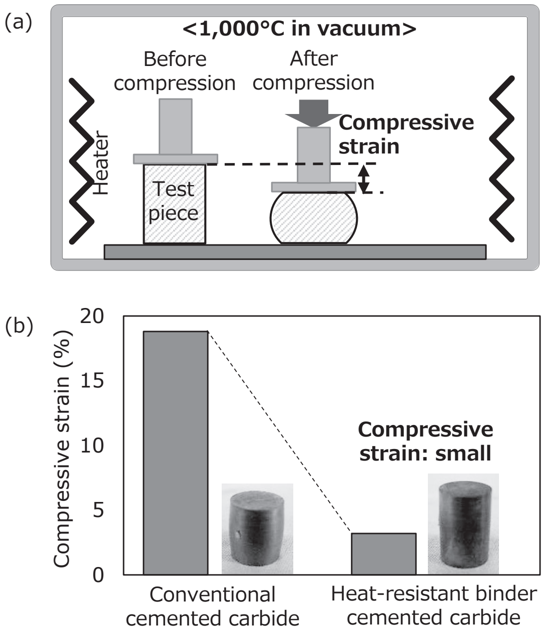
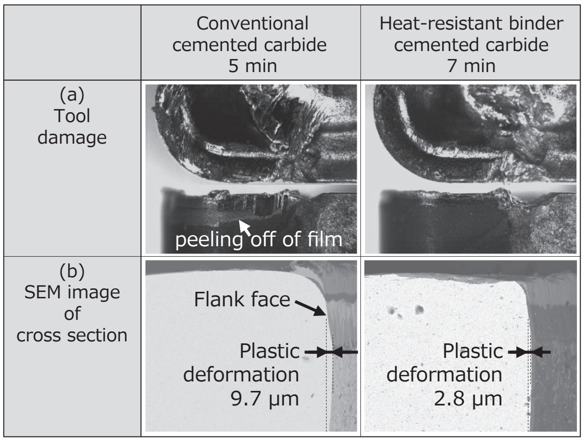
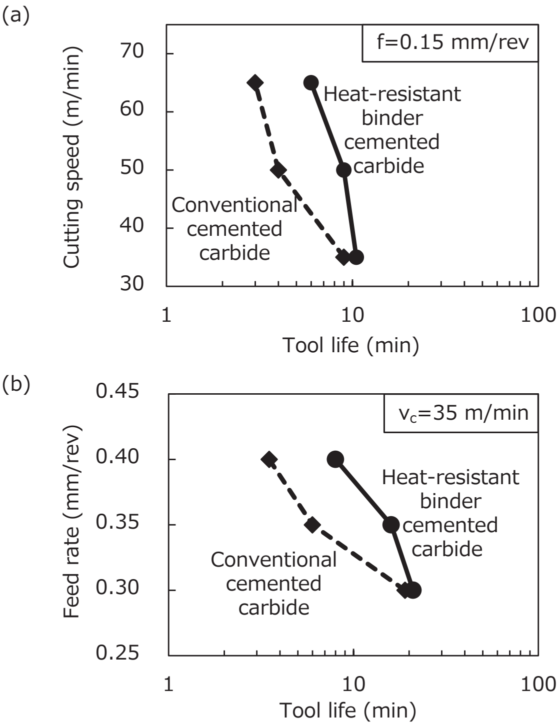


Fig. 3. (a) Schematic illustration of high-temperature compression test and (b) compressive strain and photos of the external appearance of test pieces after the test



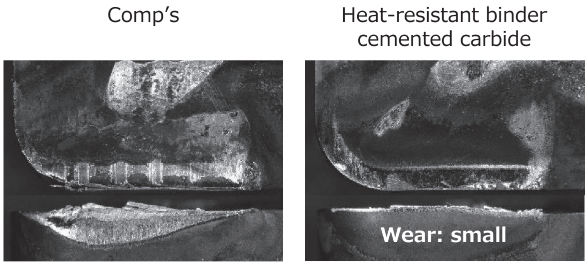
Work material: INCONEL 718, inserts: CNMG120408N-GU,
cutting speed: v_c=35 m/min (115 SFM),
feed rate: f=0.40 mm/rev (0.016 IPR),
depth of cut: a_p=1.5 mm (0.06 inch), wet

Fig. 4. (a) Photos of tool damage and (b) cross section SEM images of tools after being used for turning heat-resistant alloy



Work material: INCONEL 718, inserts: CNMG120408N-GU,
a_p=1.5 mm (0.06 inch), wet

Fig. 5. (a) v-t diagram and
(b) f-t diagram in the turning of a heat-resistant alloy



Work material: INCONEL 718, inserts: SNMG190616N-MU,
v_c=40 m/min (131 SFM), f=0.54 mm/rev (0.021 IPR),
a_p=2.7 mm (0.11 inch), wet, 10 min

Fig. 6. Comparison of tool damage in outer diameter turning of an engine shaft

when used for high-efficiency machining at high cutting speed and feed rate. An example of a heat-resistant binder cemented carbide tool used at an actual engine shaft manufacturing site is shown in Fig. 6. Thanks to its superior wear resistance, the tool achieved a machining efficiency 1.3 times and a service life 1.5 times those of tools currently made by a competitor.

3. State-of-the-Art Cemented Carbide Tool for Machining Titanium Alloys

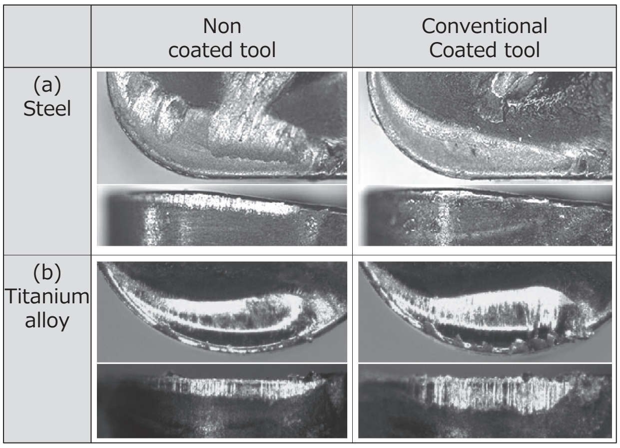
3-1 Challenges in machining titanium alloys

In the field of aircraft manufacturing, the use of innovative materials has been promoted to reduce aircraft operation costs through weight reduction. In particular, lightweight and corrosion-resistant titanium alloys are increasingly used. On the other hand, titanium alloys are classified as difficult-to-machine materials since they are chemically very active and accelerate tool damage due to reaction with the tools during machining.(2) In steel machining, coating the cutting tools dramatically suppresses damage to both the rake and flank, while in titanium alloy machining, coated material rather accelerates damage to the tool, as shown in Fig. 7. Figure 8 shows photos of damage to a coated tool that occurred in the early stage of machining. The coating was worn away in a wide area within a short period of the start of machining, verifying that titanium alloys exhibit extremely high reactivity especially when they react with a coating.

Under the above circumstances, we have developed a new coated material that rarely reacts with titanium alloys.

3-2 Features of the new coating for titanium alloy machining

Figure 9 shows the study results for cutting force in orthogonal cutting of titanium alloys.(3) Compared with the conventional coating, the new coating developed for titanium alloy machining has had lower cutting resistance. In particular, the new coating reduced the thrust force, which is significantly affected by adhesion to the cutting edge, by approximately 30%. Figure 10 shows the rake face of the cutting edge after milling of a titanium alloy. Since the



(a) Work material: SCM435, inserts: CNMG120408N-SU, v_c=240 m/min (787 SFM), f=0.20 mm/rev (0.008 IPR), a_p=1.0 mm (0.04 inch), wet, 5 min
(b) Work material: Ti-6Al-4V, inserts: CNMG120408N-EX, v_c=50 m/min (164 SFM), f=0.20 mm/rev (0.008 IPR), a_p=0.8 mm (0.03 inch), wet, 60 min

Fig. 7. Effect of coating on turning

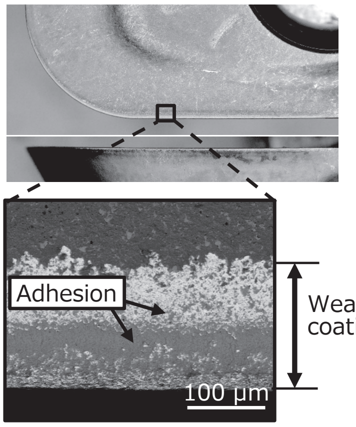
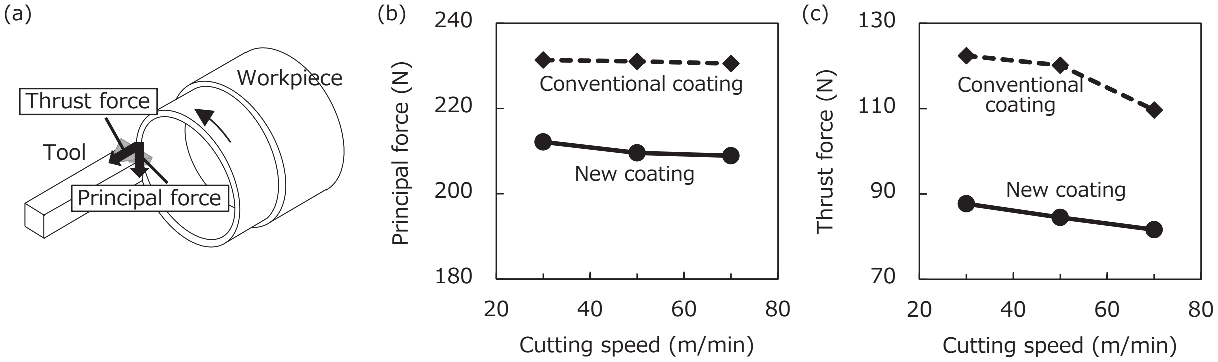
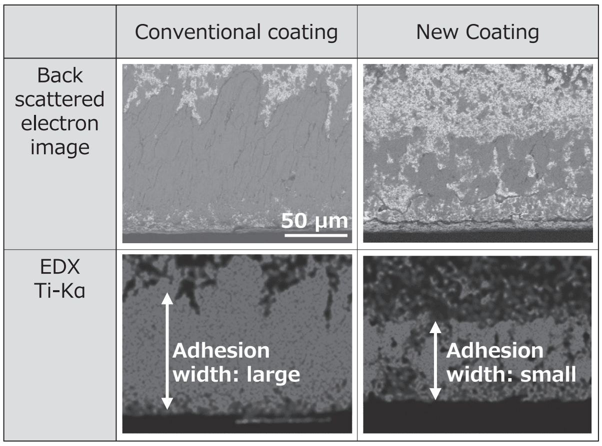


Fig. 8. Primary tool damage in titanium alloy machining



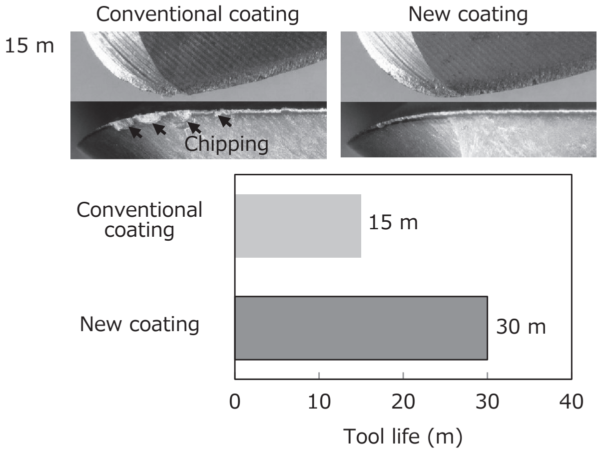
Work material: Ti-6Al-4V, inserts: TPGN220404,
v_c=30-70 m/min (98-230 SFM), f=0.10 mm/rev (0.004 IPR), cutting width: 1.0 mm (0.04 inch), dry, 10 min

Fig. 9. Evaluation results for cutting force in orthogonal dry machining of titanium alloy: (a) schematic illustration of orthogonal cutting, (b) principal force and (c) thrust force



Work material: Ti-6Al-4V, inserts: RPHT1204M0EN-G,
v_c=50 m/min (164 SFM), f_z=0.10 mm/t (0.004 IPR),
a_p=2.5 mm (0.10 inch), a_e=25.0 mm (0.98 inch), wet

Fig. 10. Comparison of adhesion on the rake face in titanium alloy milling



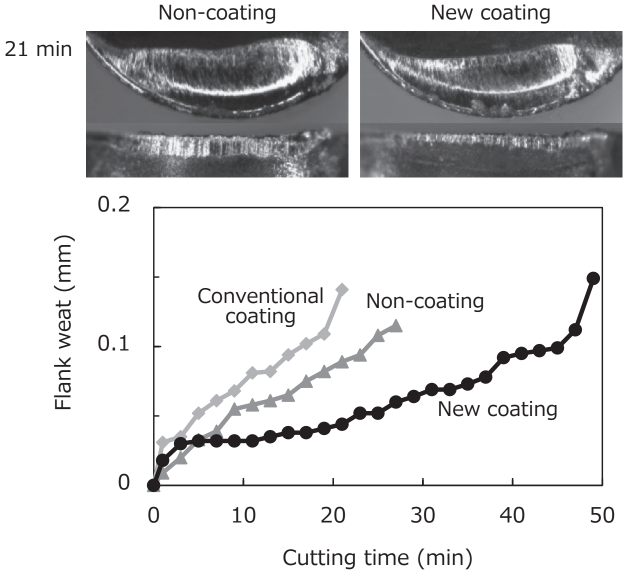
Work material: Ti-6Al-4V, inserts: SSEHV4120R-10,
v_c=10 m/min (328 SFM), f_z=0.10 mm/t (0.004 IPR),
a_p=10.0 mm (0.39 inch), a_e=2.0 mm (0.08 inch), wet

Fig. 12. Evaluation results for tool life in titanium alloy milling

adhesion width of the new coating is narrow, it is concluded that the coating reduces friction with chips and thus reduces cutting resistance. These results confirmed that the new coating has excellent reaction resistance to titanium alloys.

3-3 Performance of new coating for titanium alloy machining

The evaluation results for tool service life in titanium alloy turning are shown in Fig. 11. The new coating suppressed wear of both the rake face and flank of the tool, and increased its service life to 1.5 times or more that of conventional non-coated tools. Figure 12 shows the evaluation results for the service life of a radius endmill in side milling of a titanium alloy. The new coating reduced tool chipping due to adhesion, increasing the tool service life to twice that achieved by conventional coating.



Work material: Ti-6Al-4V, inserts: CNMG120408N-EX,
v_c=70 m/min (230 SFM), f=0.20 mm/rev (0.008 IPR),
a_p=0.8 mm (0.03 inch), wet

Fig. 11. Evaluation results for wear resistance in titanium alloy turning

4. Conclusion

This paper has described state-of-the-art cemented carbide tools suitable for machining heat-resistant alloys and titanium alloys which are widely used in the aircraft industry. In the aircraft industry, where the demand for aircraft is expected to increase in the future, the new tools are expected to contribute to our customers in terms of manufacturing efficiency enhancement and manufacturing cost reduction.

- INCONEL is a trademark or registered tradename of Huntington Alloys Corporation.

Technical Terms

∗1 Heat-resistant alloy: An alloy having excellent corrosion resistance, oxidation resistance, and strength at high temperatures. This material is used for manufacturing jet engine and gas turbine parts that are operated in high-temperature environments.

∗2 Titanium alloy: A lightweight alloy having excellent corrosion-resistance and strength. Due to extremely high specific strength (tensile strength/specific gravity), this alloy is particularly useful for manufacturing high-speed rotating bodies and aircraft parts.

∗3 Binder: A metallic component that binds tungsten carbide and other hard particles contained in cemented carbide. Cobalt or nickel is usually used as one of the components that exerts a decisive effect on the mechanical strength of cemented carbide.

∗4 v-t diagram and f-t diagram: Logarithmic charts with machining speed and feed rate plotted on the vertical axis and tool service life plotted on the horizontal axis.

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