Noritake Proposal

Featured Products and Technology

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Vitrified-bond Grinding Wheel for Titanium Alloy (Ti-6Al-4V)

Used in various fields, titanium alloy (Ti-6Al-4V) is a difficult-to-cut material with very low thermal conductivity; conductivity. Therefore, when grinding it introduces issues with maintaining surface roughness and workpiece quality, as well as shortened wheel life.
In order to deal with these issues, we would like to present vitrified-bond conventional grinding wheels and grinding conditions suitable for grinding Ti-6Al-4V.

Conventional Abrasive Grains

SH (aluminum oxide) Grain and GC (silicon carbide) Grain

[Scope of Applications and Expected Benefits]

Metallic materials		Non-metallic materials		Other
Ferrous materials	Non-ferrous materials (Al/Cu, etc.)	Inorganic materials (glass and ceramics)	Organic materials (rubber and plastic)	Advanced materials
●	●			

Shorter cycle time	Improved tool life	Improvement of workpiece quality	Improvement of workability	Environmental consideration
	●	●		

Issues with Grinding Titanium Alloy (Ti-6Al-4V)

The titanium alloy (Ti-6Al-4V, JIS60 type, subsequently referred to as "Ti-6Al-4V"), discussed in this paper contains 6% Aluminum (Al), 4% Vanadium (V) with the remainder of its mass being titanium (Ti). It is used in a wide range of fields because of its light weight, high strength, and high corrosion resistance (Table 1).

Although Ti-6Al-4V possesses these high-performance characteristics, it is also classified as a "difficult-to-cut material."

Table 1 Ti-6Al-4V Application Examples

Field	Representative example
Aerospace	Engine fan blades
Automotive	Engine valves
Energy	Turbine blades
Medical	Artificial bones, Implants
Architecture	Roofing materials
Sports	Golf drivers

Ti-6Al-4V and SCM440(JIS), a typical structural alloy steel, were ground under the same conditions. The results showed that grinding force, surface roughness, and wheel wear for Ti-6Al-4V were significantly greater in comparison to SCM440 (Table 2, Fig. 1). Also, the grinding wheel surface after grinding shows severe loading with workpiece chips and dulling of the grains (Fig. 2). The discharged chips are of the build-up type* and tearing type* (Fig. 3). Because of this, it is difficult to maintain surface roughness and workpiece quality when grinding Ti-6Al-4V, and because dressing frequency and wheel wear increases, machining costs are also an issue.

Fig. 1 Test Results

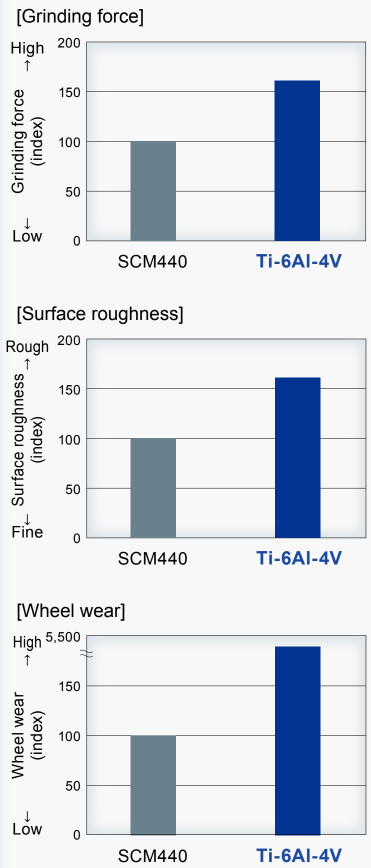
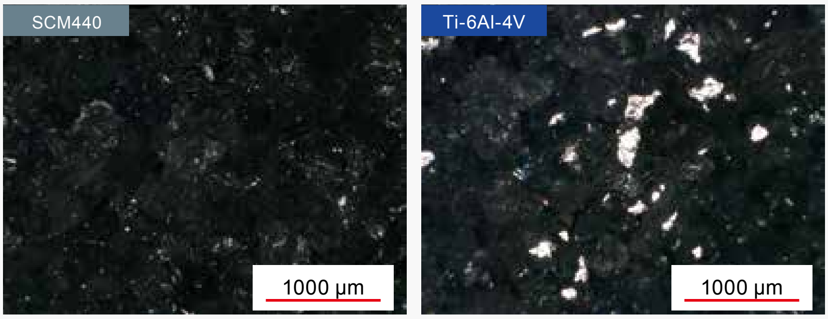


Table 2 Test Conditions

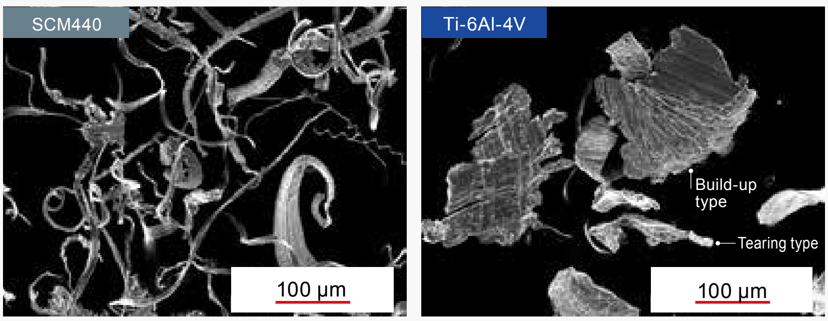
Grinding method	Surface grinding
Grinding wheel specifications	SH60-V
Wheel dimensions	φ176 × T19 × φ76.2 mm
Grinding wheel speed	30 m/s
Grinding efficiency	3.3 mm^3/mm·s
Cutting depth	0.01 mm/pass

Fig. 2: Grinding Wheel Surface Conditions after Grinding



White area: Dull cutting edges and workpiece material loading

Fig. 3: Grinding Chips



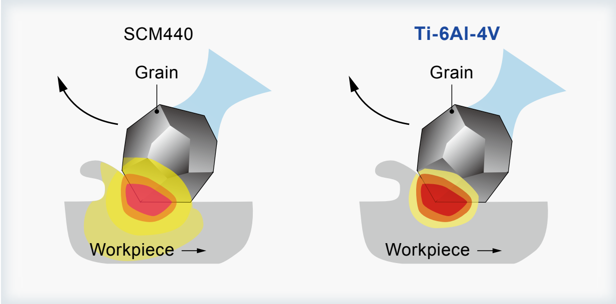
Flow-shape type grinding chips*　　Build-up type and tearing type* grinding chips

What, then, causes Ti-6Al-4V to be such a "difficult-to-cut material" as described above? Grinding heat is considered one of the major factors. It is generally said that Ti-6Al-4V has about 80% less thermal conductivity than SCM440.

If the material has relatively high thermal conductivity such as SCM440, grinding heat will diffuse from the grinding point into the workpiece as it is generated. However, because Ti-6Al-4V has low thermal conductivity, the grinding heat will diffuse much less and local temperature at the grinding point will rise (Fig. 4). This results in the rapid dulling of cutting edges, abnormal breaking down of grain, and/or loading. If a grinding wheel is used in this condition, the quality or accuracy of the workpiece surface may be compromised due to grinding burn or defects in the surface roughness or profile, resulting in problems such as shortened wheel life.

In order to mitigate these issues, we will describe below how to select the right vitrified-bond conventional grinding wheel for grinding Ti-6Al-4V.

Fig. 4 Difference in Grinding Heat Diffusion (Image)



The Best Recommendations for Vitrified-Bond Conventional Wheel for Ti-6Al-4V

Ti-6Al-4V grinding tests were conducted with three vitrified-bond conventional grinding wheel types: WA (aluminum oxide) grain, SH (aluminum oxide) grain*, and GC (silicon carbide) grain, respectively (Table 3, Fig.5). Compared to WA, a general-purpose grain, SH grain has nearly equal grinding force and surface roughness, while wheel wear is reduced by about 30%. Although GC grain has about a 50% higher grinding force than WA grain, the surface roughness is 20% finer and the wheel wear is reduced by about 70%. When checking the grinding wheel surface conditions after grinding, the SH and GC grains showed loading of workpiece material and dull grains, while the WA grain had far less of both (Fig. 6). This suggests abnormal breakdown in the WA grain, which takes place immediately after the cutting edges become dull or loading occurs, and thus, efficient grinding is not possible.

Based on these results, for grinding Ti-6Al-4V, we can recommend SH grain when cutting ability and wheel life are desired; and GC grain when the surface roughness of the workpiece and wheel life are particularly important.

Table 3 Test Conditions

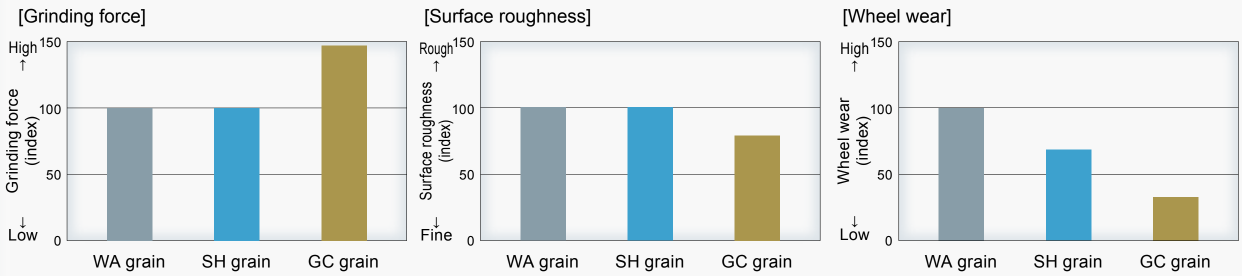
[Grinding conditions]

Grinding method	Surface grinding
Grinding wheel specifications	WA60-V SH60-V GC60-V
Wheel dimensions	φ176 × T19 × φ76.2 mm
Grinding wheel speed	10 m/s
Grinding efficiency	3.3 mm³/mm･s

[Dressing condiions]

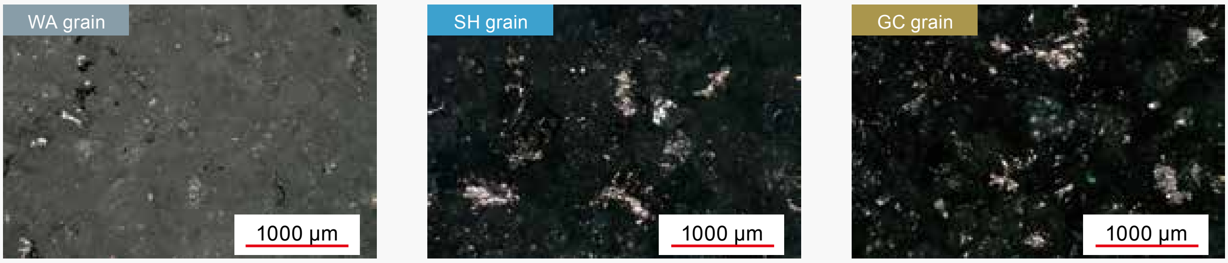
Dresser	0.6LL Single-point dresser
Dressing lead	0.1 mm/r.o.w.
Cutting depth	R0.01 mm/pass

Fig. 5 Test Results



(in the above index, WA grain value is 100%)

Fig. 6 Grinding Wheel Surface Condition after Grinding



White area: Dull cutting edges and workpiece material loading

1 For Cutting Ability and Wheel Life: SH Grain

SH grain has a hardness equivalent to that of WA grain, but is more durable (Fig. 7). With the dressing conditions shown below, the SH grain forms large cutting edges (Fig. 8), and these edges are considered a key factor in acheiving excellent cutting ability. The WA grain also forms large cutting edges, but since SH grain is more durable, it is less affected by factors that shorten wheel life such as extensive crushing and breaking down of grain. Therefore, it can be reasoned that under these dressing conditions, because SH grain is durable enough and formed large cutting edges after dressing, it can achieve sufficient cutting ability and grinding wheel life.

2 For Excellent Workpiece Surface Roughness and Wheel Life: GC Grain

GC grain is harder than WA grain (Fig. 7), and forms smaller cutting edges on grains when dressing (Fig. 8). GC grain showed better surface roughness and wheel life due to the smaller cutting edges created by dressing.

Fig. 7 Grain Characteristics (Image)

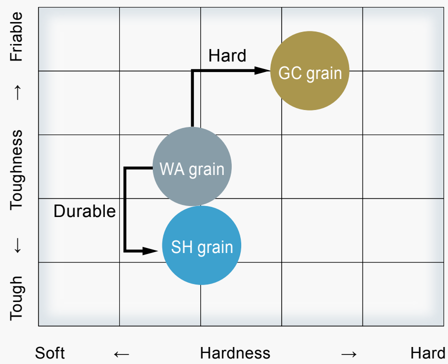
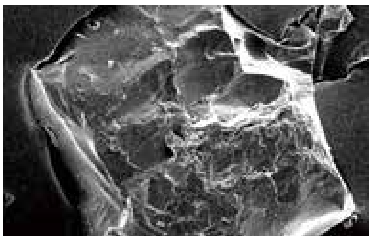
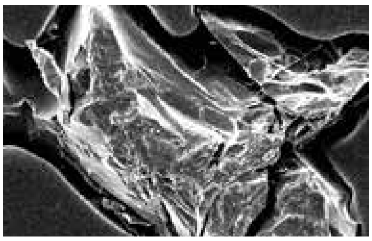
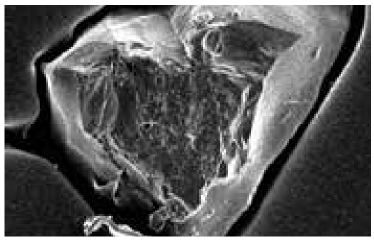
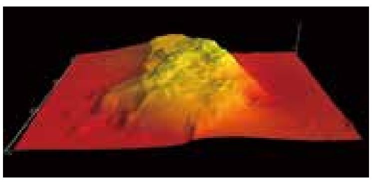
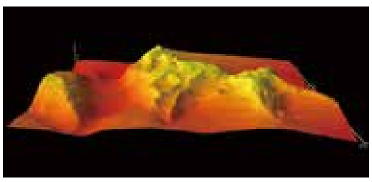
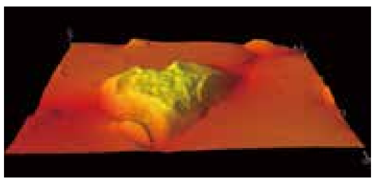
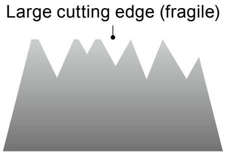
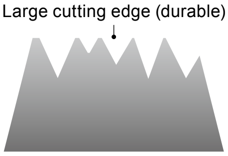
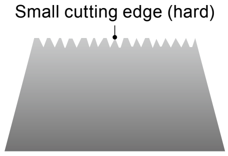


Fig. 8 Grain Status and Cross-Sectional Image after Dressing

	WA grain	SH grain	GC grain
SEM (scanning electron microscope) image of grain			
3D image of grain			
Cross-sectional image of grain	Large cutting edge (fragile)  Short grinding wheel life	Large cutting edge (durable)  Excellent cutting ability and grinding wheel life	Small cutting edge (hard)  Superior workpiece accuracy and grinding wheel life

In summary, the difference in each wheel's grinding performance is due to its particular abrasive characteristics and the size of the cutting edges formed by dressing.

Optimal Wheel Speed when Grinding Ti-6Al-4V

We've shown how to choose the best vitrified-bond conventional grinding wheel for grinding Ti-6Al-4V, but no matter how good the grinding wheel is, it can't perform at its best without the correct grinding conditions. This section describes the appropriate grinding conditions.

By using vitrified-bond SH grinding wheels on Ti-6Al-4V and changing the grinding wheel speed, we found that the surface roughness of the workpiece tends to be finer when the wheel is faster and wheel wear tends to be reduced when it is slower (Table 4 and Fig. 9). In other words, if accuracy is prioritized, like when a precise surface roughness is desired, it may be better to increase the grinding wheel speed; and if wheel wear and cost reduction are prioritized, it may be better to decrease the grinding wheel speed.

To further explain the results, when the grinding wheel speed is fast, the surface roughness of the workpiece generally tends to be finer because the depth-of-cut is shallower. In fact, by changing the grinding wheel speed from 10 m/s to 30 m/s in this test, depth-of-cut is reduced to approximately 1/3 and the surface roughness of the workpiece becomes finer. Wheel wear also tends to be reduced when the depth-of-cut is shallow (when the grinding wheel speed is fast), but this result is a little counterintuitive. This may be related to the lower thermal conductivity of Ti-6Al-4V. If the grinding wheel speed is fast and the depth-of-cut is shallow, the grain tends to dull during grinding. Grinding with dull cutting edges tends to generate grinding heat, particularly in materials with low thermal conductivity such as Ti-6Al-4V. The grinding heat generated in this way actually promotes more dull cutting edges of the grain, causing loading.
By inspecting the grinding wheel's surface condition after grinding, we can confirm that more dull cutting edges and/or loading forms at a grinding wheel speed of 30 m/s (Fig. 10). Under these conditions, the grinding force applied on the grains during grinding becomes greater than the holding force of the grains, resulting in more grains breaking down.
By repeating these conditions, we can conclude that high wheel speed increases the amount of wheel wear.

Table 4 Test Conditions

[Test conditions]

Grinding method	Surface grinding
Grinding wheel specifications	SH60-V
Wheel dimensions	φ176 × T19 × φ76.2 mm
Grinding wheel speed	10 m/s 30 m/s (Depth-of-cut decrease of about 1/3)
Grinding efficiency	3.3 mm³/mm・s

[Dressing condiions]

Dresser	0.6LL Single-point dresser
Dressing lead	0.1 mm/r.o.w.
Cutting depth	R0.01 mm/pass

Fig. 9 Test Results

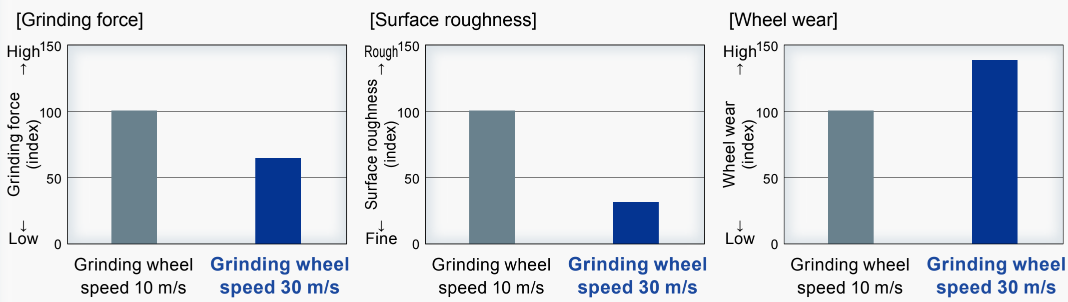
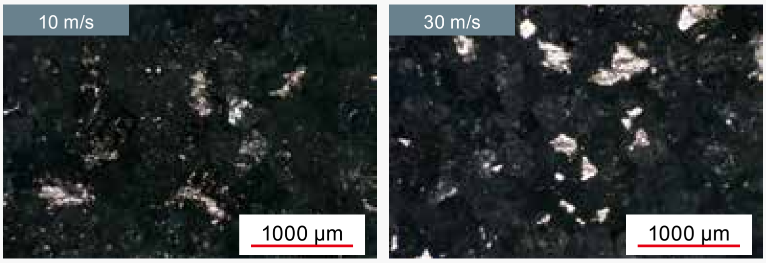


Fig. 10 Grinding Wheel Surface Condition



White area: Dull cutting edges and workpiece material loading

Addressing the Issues Encountered when Grinding Ti-6Al-4V

This article has broken down the difficult-to-grind properties of Ti-6Al-4V, and presented vitrified-bond coventional grinding wheel specs and conditions suitable for grinding this material. Because Ti-6Al-4V has a low thermal conductivity, it is difficult to maintain the accuracy and quality of the workpiece, and the grinding wheel life becomes shorter. These problems can be solved by using a vitrified-bond conventional grinding wheel composed of SH grain when both cutting ability and grinding wheel life need to be maintained; or composed of GC grain when workpiece surface roughness or grinding wheel life are prioritized. Similarly, grinding conditions can be adjusted by increasing the grinding wheel speed to improve workpiece surface roughness, and decreasing it to improve wheel life.

[Notes]

* Flow-shape type grinding chips: Ribbon-like chips that occur under ideal grinding conditions.
* Build-up type grinding chips: Loading chips that build up against the grains on the grinding wheel.
* Tearing type grinding chips: Powder-like chips that occur under poor grinding conditions.
* SH grain: Single-crystal alumina-based grain, which is less susceptible to crushing than WA grain.

[References]

[1] Yusuke Oura: Super Uniform, Non-Clotty, NORITAKE TECHNICAL JOURNAL 2018 (2017), 8-11

Q **What's the most efficient way to grind Ti-6Al-4V?**

A In addition to the suggestions in this article, we also propose the following methods.

①Changing to Super Uniform or Non-Clotty [1] wheels with more homogenous structures can suppress the dulling of abrasive grains and loading caused by grinding heat.

②The addition of a high-pressure coolant nozzle (scrubber) can reduce loading generation and build up.

Q&A