Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (18): 3774-3777, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.3774.3777

Study on the Cutting Performance and Machinability of Gamma Titanium Aluminide

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Abstract: γ-titanium aluminide alloy has advantages of high temperature resistance, high performance of anti-oxidation effect, low-density, high specific strength and rigidity etc. This material is suitable to be applied in aeronautics, astronautics and automobile industry. However its high hardness, brittleness and mechanical strength bring great difficulty in machining which is particularly outstanding in deep hole drilling. This article has analyzed the cutting performance and the machinability of γ-titanium aluminide and designed a deep-hole drill with three different tool materials. The experimental result shows: (1) YG8 cemented carbide is the appropriate tool material for drilling γ-titanium aluminide, (2) Small rake angle of external edge ($\gamma_o = -1°$) and big clearance angle of external edge ($\alpha_o = 10\sim12°$) should be chosen and (3) Best wear results are obtained when oil is utilized as cutting fluid.

Key words: γ-titanium aluminide, deep hole drilling, deep hole drills, cemented carbide

INTRODUCTION

γ-titanium aluminide alloy is a new intermetallic compound structural material which has many superiorities. Such as γ-titanium aluminide is a relatively low density alloy (3.9~4.1 $g\ cm^{-3}$) with high strength and rigidity in high temperature environment. For the good antioxidant properties (superior to titanium alloy) and great fire retardant property, these characteristics stand a good chance that γ-titanium aluminide may become an ideal material in aerospace domain and automobile industries scale (e.g., turbine blade, valve, connecting rod, turbocharger and piston pin)with partly replacing the high-temperature titanium alloy and nickel base superalloy. Therefore γ-titanium aluminide is supposed to be the most perspective high-temperature structural material at 21 centuries.

Although, γ-titanium aluminide has many excellent mechanical performance (higher red-hardness, low-density, great corrosion resistance and high temperature properties), its hard cutting performance (high cutting temperature, large cutting force, poor hot ductility and fracture toughness and fast tool wear) is crucial for its application.

Deep-hole drilling is a special method of metal machining which plays an important role in manufacturing industry. Because of the big length-diameter ratio and narrow space between the drill bit and workpiece, there are some difficulties in deep-hole drilling which include: cutting heat spill out of the workpiece difficultly, hard to remove debris, low rigidity of process system etc. (Wang and Zhu, 2003). These unfavorable factors cause a decline in cutting lifetime and cutting efficiency. Therefore, deep-hole drilling on γ-titanium aluminide was chosen as the research object. Through experiment and research, we can get the optimal parameters (tool material, geometric parameters of the drill and cutting dosage) of deep-hole drilling γ-titanium aluminide.

STUDY AND TEST

The cutting performance is the difficult degree of machining of materials. In production, the relative cutting performance (K_V) is used to indicate the difficult degree of materials:

$$K_V = \frac{v_{60}}{(v_{60})_j} \tag{1}$$

v_{60} is the cutting speed when the tool life is 60 min, $(v_{60})_j$ means the cutting speed for 45#steel ($\sigma_b = 0.75$ Gpa) when the tool life is 60 min. Smaller K_V is, more difficult the cutting is. At present, the materials can be divided into 4 classes, γ-titanium aluminide (Ti-44.5Al-0.5Mo-1.0 Cu-0.2Si) and TiAl6V4 (TC4) belongs to awfully hard-cutting materials. Because of the plasticity of γ-titanium aluminide is poorer than that of titanium alloy (TiAl6V4), in a way the cutting of γ-titanium aluminide is more difficult than titanium alloy (TiAl6V4).

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Because of its low thermal conductivity and short contact distance between chips and rake, the cutting heat saves in the cutting field which leads to a higher cutting temperature. The cutting force per unit area of γ-titanium aluminide is bigger than other materials which may lead to the tipping of tools. We can clearly understand its mechanical performance by seen Table 1 (Weinert and Biermann, 2008). The axial force comparison of drilling γ-titanium aluminide, titanium alloy (TiAl6V4) and 45 steel is shown in Fig. 1 (Opalla, 2003; Weinert *et al.*, 2007). Axial force of drilling γ-titanium aluminide was 2 times compared with that of titanium alloy when drilling speed is 60 m min^{-1}. And the axial force was 4 times larger than drilling 45 steel when drilling speed is 100 m min^{-1}. The surface of workpiece was even disintegrated sometimes. The main cause of this is low elongation. It is shown in Fig. 2.

As other superalloy materials, γ-titanium aluminide is extremely vulnerable work hardening, for poor toughness and elongation, crack and flaking may emerge on workpiece surface and these all cause a fall of the surface quality. Further more, its Young modulus is relatively small and elastic deformation is large, this leads a serious friction between the flank and machined surface which then leads a decline of the surface finish.

The design of deep-hole drill: Drill bit plays a significant role in the deep-hole drilling system. The selection of tool material together with the choosing of the angle of drill bit mainly composes the design of deep-hole drill.

Table 1: Mechanical performance comparison

Performance	γ-TiAl	TiAl6V4	Inconel718
Density (g cm^{-3})	3.7~3.9	4.5	8.2
Young modulus (Gpa)	165	110	206
Elongation (%)	1.2~4.2	14.3	25
Tensile strength (Mpa)	900	950	965
Yield limit (Mpa)	790	917	1000
Hot Ductility (%)	10~800	12~25	20~870
Creep limit (°C)	750~950	600	950

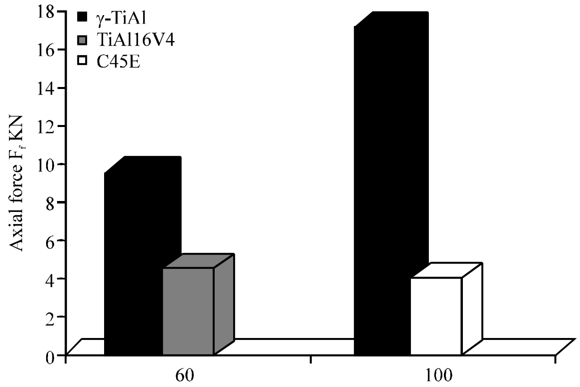

Fig. 1: Axial force comparison

The material of blade: Considering the lack of experimental data, this article chose three kinds of cemented carbide (YG8 cemented carbide, YW2 cemented carbide and YG813 cemented carbide) which are respectively suitable for processing titanium alloy, molybdenum alloy and superalloy. Then we can find out the appropriate tool material by drilling experimental:

- YG8 cemented carbide is the most commonly used cutting tools for processing titanium alloy. It has high strength and is hard to react with titanium
- YW2 cemented carbide called "universal cemented carbide" has the advantages of good high temperature properties, higher strength and impact toughness. YW2 cemented carbide has performed well in machining some new materials. It is widely used in processing difficult-to-machine materials
- Since, YG813 cemented carbide has excellent wear resistance, higher bending strength and anti-adhesion performance, it is suitable for processing superalloy. Its effect of machining austenite stainless steel and high manganese steel is better than YW2 cemented carbide

Angle of drill bit: For the bigger drilling force, the cutting edge shouldn't too sharp. Rake angle should be 0° or smaller negative degrees. Smaller rake angle will increase the cutting lifetime and cutting speed. In addition, the lower elastic modulus and larger elastic deformation caused serious friction between machined surface and flank, therefore we chose bigger clearance angle of external edge. The geometric parameters are shown in Fig. 3. Diameter of the drill is 12 mm, rake angle of external edge $\gamma_0 = -1°$, clearance angle of external edge $\alpha_0 = 10\sim12°$.

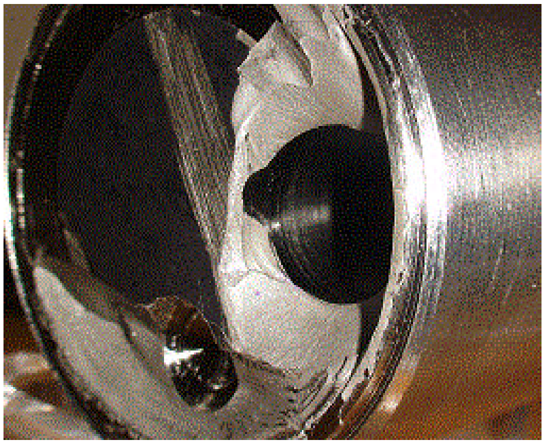

Fig. 2: Outlet of the hole was disintegrated

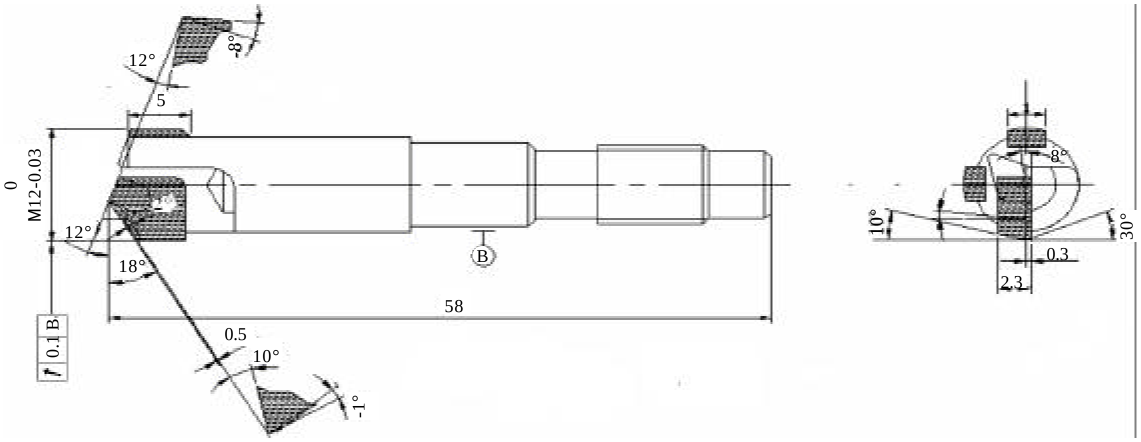

Fig. 3: Geometric parameters of the deep hole drill

Fig. 4: Φ 12 mm deep hole drill

Experimental conditions: The deep hole drilling machine was retrofitted by C630 lathe. The maximum rotor speed is 3000 r min^{-1}. The minimum feed rate is 0.005 mm r^{-1}. The drill bit is shown in Fig. 4.

The material of workpiece is Ti-44.5Al-0.5 Mo-1.0Cu-0.2Si. Drilling speed V = 38 m min^{-1}, Feed rate V_f = 0.015 mm r^{-1}, Diameter of the drill d = 12 mm, Cutting fluid is cutting oil, the measuring instruments are resistance strain drilling dynamometer and tool microscope.

Experimental methods: Use the same cutting parameter and drilling depth carried deep hole drilling experiments on γ-titanium aluminide with three different materials of blade, then measured axial forces, tool wear condition and the processed holes' size.

RESULT AND ANALYSIS

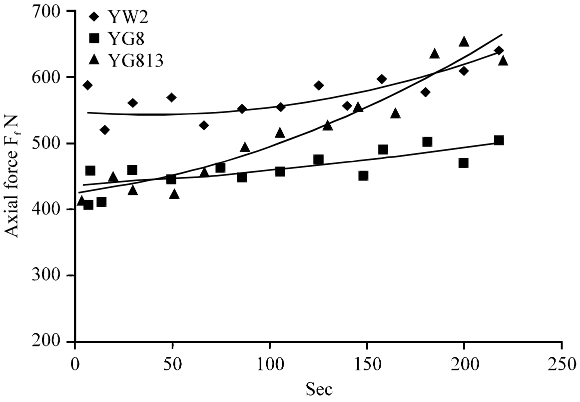

Fig. 5: Axial force comparison

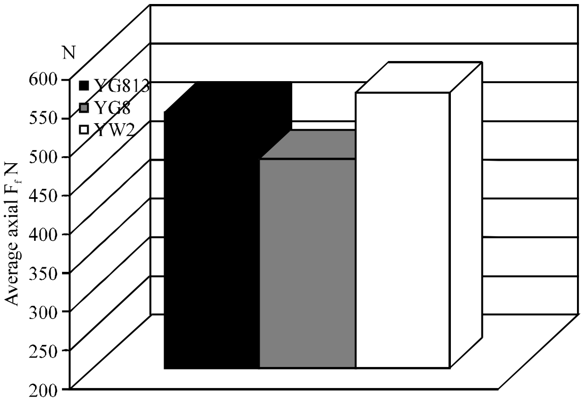

Fig. 6: Average axial force comparison

At first the axial forces were measured. The axial forces comparison of YG8 cemented carbide drill, YW2 cemented carbide drill and YG813 cemented carbide drill was shown in Fig. 5. In Fig. 5, the axial force of YG813 drill changes from the smallest up to the biggest during the fourth min. This means that the fastest wear will happen when used YG813 cemented carbide. The average axial forces comparison was shown in Fig. 6 which shows that average axial force of YG8 cemented carbide is the smallest.

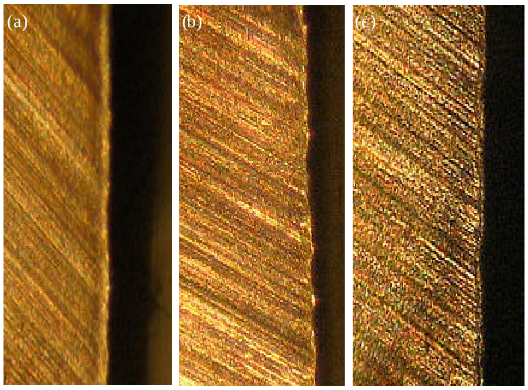

Fig. 7(a-c): Wear of flank surface (a) YG813 (b) YG8 and (c) YW2

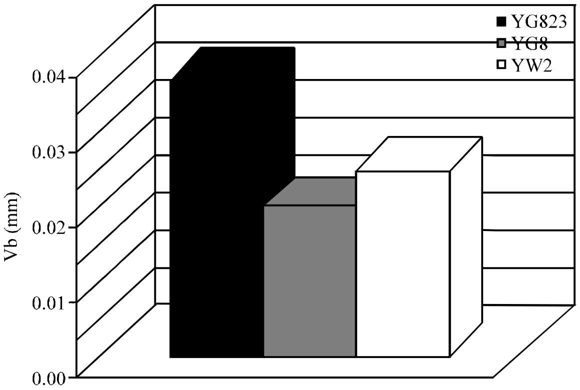

Fig. 8: Width of wear land VB

Figure 7 shows the wear (caused by cutting heat, mechanical friction and cutting force) on flank surfaces. The widths of wear land (VB) are shown in Fig. 8. The VB of YG813 cemented carbide is the maximum while the minimum VB are obtained by used YG8 cemented carbide. This result corresponds with the variations of axial force (Fig. 6). After analysis, there are two possible reasons for the difference in wear behavior. First, YG813 cemented carbide (K10~M10) and YW2 (M20) cemented carbide belong to M series cemented carbide, M series cemented carbide contain TiC and then chemical affinity between Ti (from workpiece) and TiC made the wear patterns (of YG813 and YW2) more serious than YG8 (contains none TiC). The second reason is that YG8 cemented carbide has higher density and thermal conductivity.

Table 2: Expand value of inside diameter

Materials of drill	YG813	YG8	YW2
Diameter of the drill (mm)	11.960	11.99	11.95
Diameter of the hole (mm)	12.119	12.05	12.15
Expand value (mm)	0.159	0.06	0.20

The expand value of inside diameters, diameter of the drill bits and diameter of holes are shown in Table 2. These data proved that drilling quality was also concerned with tool materials, the reason may be that different materials have different drilling radial forces. The smallest expand value can be achieved when used YG8 cemented carbide.

CONCLUSION

On the foundation of materials of blade, this article studied the deep-hole drilling on γ-titanium aluminide by experiment. Excellent mechanical performance and the particularity of deep hole drilling lead to high cutting force and serious wear behavior. The result shows that YG8 cemented carbide is more suitable for drilling γ-titanium aluminide in comparison to YW2 cemented carbide and YG813 cemented carbide, the reason is YG8 cemented carbide could reduce drilling force and tool wear. In addition, for the lower elastic modulus, poor thermal conductivity and high red hardness, we should chose small rake angle (γ_0 = -1°) and big clearance angle of external edge (α_0 = 10~12°).

Furthermore, best wear results are obtained when oil is utilized as lubricant.

REFERENCES

Opalla, D., 2003. Hochleistungsbohren metallischer werkstoffe mit wendelbohrern. Dissertation, Universitat Dortmund Vulkan Verlag, Essen, 2003.

Wang, S.Q. and L. Zhu, 2003. The Deep Hole Processing Technology. Press of North-West Polytechnic University, Xi'an, pp: 52-68.

Weinert, K. and D. Biermann, 2008. Spanende Fertigung, 5. Ausgabe. Vulkan Verlag, Essen.

Weinert, K., D. Biermann and S. Bergmann, 2007. Machining of high strength light weight alloys for engine applications. CIRP Ann. Manufact. Technol., 56: 105-108.