Drilling Titanium Aluminides with Twist Drills

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Abstract: Due to their high strength/weight ratio and resistance to corrosion and wear, superalloys such as gamma TiAl or Inconel 718 appear as the best choice at the sight of the demands in the vicinity of the combustion chamber. Such kind of parts suffer one last drilling operation at the end of the manufacturing process. The present work is framed within the study of twist drilling in advanced materials used for lightweight applications in aerospace sector. Within this context, the paper presents the results obtained from different tests in gamma TiAl alloys. Tool life tests were performed on three types of γ -TiAl (extruded MoCuSi, ingot MoCuSi and TNB) to define an optimal set of cutting parameters.

Key words: Gamma TiAl, drilling, slight materials, superalloys.

1. Introduction

The interest of the air transport industry focused on the research of new materials that would open the way to support more demanding service conditions with the simultaneous target of lighter aircrafts.

Regarding to the aircraft engine, γ -TiAl intermetallic superalloys appear as a valid alternative in direct competition with nickel-based superalloys (Inconel, Waspalloy) where service temperatures exceed 800 °C. These alloys find their market in the high pressure area (compressor blades and stator) as well as in the low pressure zones (blades). The binomial TiAl provides a low density as well as high mechanical strength under high temperatures and corrosive environments [1]. These are complex alloys with high sensitivity to non-metallic impurities such as oxygen which need to be studied further.

The main difference between γ -TiAl alloy and other alloys such as Ti-6Al-4V lies on the aluminum levels (43-48% in γ -TiAl and 6% in Ti-6Al-4V) which improves thermal conductivity in γ -TiAl, but

worsening the ductile transition temperature which occurs between 600-800 °C depending on the microstructure and grain size.

In solid state, titanium alloys are found as alpha HCP (hexagonal close-packed structure) or beta BCC (body-centered cubic structure) phase. In pure state, the transition temperature between two phases is found at 882 °C, TiAl couple enabling solid solution hardening. Aluminum is the most common alloying element because of its ability to raise the beta transition temperature and its high solubility in both phases. Besides the alpha and beta phases, alpha2 or Ti_3Al and intermetallic gamma phase appear, both of capital significance in high temperature aerospace applications. The latter one is a face-centered cubic (FCC) L10 phase whose homogeneity ranges between 34% to 55% (% in weight). Fig. 1 shows the relationship between microstructure and phase. The aluminum, oxygen, hydrogen and other alpha stabilizers increase the transition temperature between alpha/beta phase. On the other hand, beta-stabilizers (beta-eutectoid and beta-isomorphous) reduce the transformation temperature, causing a stable beta phase at room temperature.

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Fig. 1 Tool life in extruded MoCuSi (TL = Tool Life).

The following paper deals with the study of the behaviour of complex difficult-to-cut superalloys such as γ -TiAl [2]. Tool life tests have helped in defining a suitable set of parameters in drilling of three different types of γ -TiAl (extruded MoCuSi, ingot MoCuSi and TNB).

2. Twist Drilling of γ -TiAl Superalloy

The intermetallic gamma TiAl superalloys offer excellent mechanical properties [1], with low density (4 gr/cm^3), high resistance at high temperatures, low electrical and thermal conductivity, oxidation resistance, ultimate strength of 1000 Mpa and Young's modulus of 160 Gpa [3]. There are three basic types of γ -TiAl superalloys: TNB [(44-45)Al - (5-10)Nb - (0.2-0.4)C], sustaining high levels of mechanical and oxidation resistance and used in aircraft applications at high temperatures [4, 5]; MoCuSi type [(43-46)Al - (1-2)Mo - (0.2)Si-Cu], for low temperatures applications and with high resistance below 650°C ; finally, TNM [(43-45)Al - (5-8) Nb - Mo - (0-0.4)BC] for high temperature applications. There are two ways to manufacture these materials: solidified ingot or extruded alloy. In the first case, the alloy has the microstructure oriented in the direction of extrusion whereas in the case of melted and solidified alloys in the mould, the microstructure has no preferred orientation.

These materials are known by their low machinability and a study of the optimal cutting conditions [6] seems necessary. Table 1 shows the basic cutting data investigated during the experimental drilling tests. A set of optimal cutting parameters for a

Table 1 Tests procedure: M1 = extruded MoCuSi, M2 = ingot MoCuSi, M3 = TNB.

V_c (m/min)	f_n (mm/min)				
	0.025	0.038	0.050	0.100	0.150
10	M1,M3	M1,M3	M1,M2,M3	M1,M2,M3	M2, M3
15	M1	M1	M1,M2,M3	M1,M2,M3	
20	M1	M1	M1,M2,M3		
25	M1				

reasonable tool life were obtained in extruded MoCuSi, ingot MoCuSi and TNB [7].

Tests were carried out using carbide tools whose main geometrical characteristics are shown in Fig. 2. One of the critical aspects when drilling γ -TiAl is heat dissipation and chip evacuation due to the poor thermal conductivity.

Concerning this aspect, cutting tools are endowed with internal lubrication directly applied on the cutting edge, favouring chip evacuation. The cutting tools used were drills of $\varnothing 4$ and TF15 quality with Young's modulus of 580 GPa and MIRACLE (Al, Ti)N coating type. The operations were performed for a depth of 20 mm ($D/L = 5$) under a pressure of 8.5 bar for the refrigerant. The wear was observed with a microscope and the measurements were made on the digitized image of the tool. The well-known criterion $V_B = 0.3$ of flank wear width, typical for turning/drilling operations, was employed: values above 0.3 mm were considered unacceptable. Figs. 1-3 show the wear curves under different cutting speeds for the three types of γ -TiAl alloys.

Table 2 shows that for the same cutting conditions, the tool has a longer life, 3 times higher when machining MoCuSi ingot than in TNB. In general, for

Fig. 2 Tool life in ingot MoCuSi (TL = Tool Life).

Fig. 3 Tool life in TNB (TL = Tool Life).

Table 2 Tool life and wear vs materials/cutting conditions.

V_C (m/min)	f_n (mm/rev)	Extruded MoCuSi		Ingot MoCuSi		TNB	
		Time (min)	Wear (μm)	Time (min)	Wear (μm)	Time (min)	Wear (μm)
10	0.025	66	55	-	-	28	209.2
	0.038	13.3	52.4	-	-	17.8	95.7
	0.05	5.5	58.6	27.5	208	9.5	85
	0.1	3	60	5	168.5	4.5	83.7
15	0.025	20	46	-	-	-	-
	0.038	8.3	31.2	-	-	-	-
	0.05	2.4	30	11.6	96	8	79.9
	0.1	-	-	2	93	0.5	55.4
20	0.025	19.5	71.5	-	-	-	-
	0.038	-	-	-	-	-	-
	0.05	-	-	0.25	71.5	2	63.5
	0.1	-	-	-	-	-	-
25	0.025	0.4	39.3	-	-	-	-
	0.038	-	-	-	-	-	-
	0.05	-	-	-	-	-	-
	0.1	-	-	-	-	-	-

the three materials it can be stated that the optimal speed range is between 10-15 m/min [8]. Higher speeds lead to accelerated wear of the tool, except in the case of extruded MoCuSi where machining times are about 20 min when $f_n = 0.025$ mm/rev.

Another aspect is the strong tendency of the drill to torsion failure which is very sensitive to an increase in

cutting speed. This failure occurs catastrophically at approximately 45° of the profile of the drill.

Based on the results from above, the following conditions are recommended for each of the materials:

Extruded MoCuSi: $V_C = 10\text{-}15$ m/min, $f_n = 0.025$ mm/rev

MoCuSi ingot: $V_C = 10\text{-}15$ m/min, $f_n = 0.050$.

mm/rev

TNB: $V_C = 10\text{--}15$ m/min, $f_n = 0.025$ mm/rev.

3. Conclusions

During the present study was possible the evaluation of the hole making process on the difficult to cut γ -TiAl alloys with tungsten carbide coated tools using twist drilling. The results obtained offer feasible cutting parameters for the conventional drilling. From the results it is possible to conclude the ball helical milling process, previously studied for difficult to cut materials such as Inconel 718 as well as Ti6Al4V, showed a better advantage over the conventional drilling process in terms of tool life and process performance, avoiding the use of subsequent processes commonly used after drilling to remove the burrs.

The brittle behaviour of the TNB alloy was evident during simple hole making tests, even without a very high compressive stress process on an apparently strength plate 13.5 mm thick. Results make evident the current application scope of γ -TiAl alloys, and the inherent risk found during the machining of high added value and high liability workpieces.

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