Experimental analysis and optimisation of tool wear

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However, the use of cutting fluids in etal working operations may seriously degrade the quality of the environment. Consequently, many governments recommend the manufacturers to reduce the volume and the toxicity of their cutting fluids. Up to now, dry machining has remained a real challenge for the industrial world, particularly in aerospace engineering. The experimental approach taken in this study resulted in the development of both optimised tool geometry and optimised cutting conditions for drilling aluminium alloys without the need for lubrication.

The experimental investigations were carried out with WC-Co cemented carbide drills. The use of diamond as coating material allowed to extend the tool life.

The combination of the optimised tool geometry and the cutting conditions entails a high surface quality, a good dimensional accuracy of the machined material and ensures a long lifetime to the drill. Besides, a numerical calculation with Third Wave AdvantEdgeTM finite element software was used to predict the tool-chip interface temperature, which is the major parameter inducing tool wear in dry drilling. 2003 Elsevier Science B. V. All rights reserved. Keywords: Dry machining; Tool wear; Adhesion wear; Optimised drill geometry 1.

Introduction Machining aerospace aluminium alloys (series 20xx) with conventional tools is not carried out without any difficulties. These materials tend to adhere to the tool surface and burrs are formed inside the holes [1-4]. The tool damage is mainly caused by the formation of an adhesion layer and a built-up edge (BIJE) entailing a reduction of the tool life.

Thus, cutting fluids have an important role in machining process, because they contribute to [5-8]: the reduction of friction in the tool-workpiece contact, the removal of chips from the tool rake face, the decrease in temperature in the contact zone, nd the limitation of the chemical species diffusion from the tool towards the chip and vice versa. However, using cutting fluids seriously degrades the environment quality and increases the cost of machining (lubrication represents 16-20% of the product cost [9]).

As a result, dry machining has been widely studied in the last few years. Dry machining and especially dry drilling represents * Corresponding author. Tel. : +33-5-56-84-54-48; fax: +33-5-56-84-53-66. E-mail address: bordeaux.

ensam. fr (M. Nouari). a real challenge for manufacturers, so many companies and aboratories set up research programs in order to understand the phenomena brought into play. The first results enable to adapt machines and cutting tools to this new process.

The LAMEFIP laboratory of Bordeaux (France) launched a program aiming at the optimisation of dry drilling of aluminium alloys. To control dry drilling of aluminium alloys, it is necessary: (1) to limit the generation of heat that activates the diffusion of chemical species between tool and chip, and (2) to facilitate the removal of chips from the cutting area. The generation of heat mainly depends on the tool geometry, the utting conditions and the tool-chip friction.

The last one being dependent on the cutting conditions, the temperature and the nature of the contact surfaces [10]. This study intends to prove that drilling without cutting fluid is feasible with an optimised shape of drill and with optimised cutting conditions.

Several experiments under various cutting conditions are conducted in Section 2. An aluminium alloy material and different carbide drills (coated and uncoated) were tested. Following a detailed statistical analysis of the experimental results, a new drill geometry was found.

The tests carried out with this new geometry, in Section 3, allow one to obtain the optimal cutting conditions for those with a low roughness (65 m/min), the average roughness remains constant for the drills A-F-G, and increases for the other tools. According to the results of the statistical design, we can say that the surface roughness is mainly controlled by the point and helix angles.

Then, increasing these two parameters can minimize roughness. An important reduction of the burr height (Fig. 2b) is observed for the drill E (V = 165 m/min).

Concerning the drills A, C and F the lowest alues ot the burr height is observed tor the optimal velocity Vopt denned above. It is important to note that the tool E has the largest point angle (180 0 and this contributes to minimize the burr height. This result is in a good agreement Table 1 Drill types and principal characteristics Name Type Manufacturer Coating Flute shape Helix angle (o) Point Lip relief Web thickness (mm) Margin width

Number of lips Drill TF (KCD) Step drill Super drill MAE Kennametal labro tool HAM France MMC metal France None AI)N AI)N + wac Diamond TIN + Ag TIN Helical Four flutes 10 130 180 140 6.

10. 15 4. 6 10. 8 0. 0. 45 0.

37 0. 21 0. 6 0. 65 M. Nouan et al.

/ wear 255 (2003) 1359-1368 1361 g 2 Variation ot the average roughness, the burr height, the maximum and minimum diameter deviations with respect to the cutting speed V for different kinds of tools. The workpiece is an aluminium-copper alloy AA2024 T351 and the feed rate f = 0. 04 mm. with the experiments of Ko and Lee [3]. Fig. 2c and d show the average of minimum and maximum diameter deviations.

After having drilled 500 holes, the analysis of the results enabled to release the following tendencies: tain an important reduction of the minimum deviation, and onsequently a good dimensional accuracy of the holes can be obtained. The maximum diameter deviation (Fig. 2c) depends on the lip relief angle, the lips number and the web thickness. Decreasing the lip relief angle and increasing the other parameters allow to minimize the maximum diameter deviation. The minimum diameter deviation (Fig.

2d) compared to the theoretical diameter depends on the helix angle, the lips number and the web thickness.

Decreasing the web thickness and increasing the other parameters allow to ob- 2. 2. 2. Influence of the drill material coating on holes quality The kind of coating material is an important parameter to be considered to optimise the tool performance. The coatings are mainly used to increase the tool life but may influence the holes quality.

In our experiments, the following coating materials were tested: (T’, AI)N: It is deposited on the tool surface by the PVD process, and acts as a thermal barrier between the tool 1362 and the chip (thermal conductivity is about 0. 5 kW/m K). Advanced wear resistance with increased oxidation resistance of this coating offer an advantage for dry machining of cast iron, alloyed steel and aluminium with 10% of Si; ecause of its low thermal conductivity, most of the heat is evacuated by the chips.((Ti, AI)N + WC/C): It is a multi-layer coating. The combination of hard/ soft coating layers improves the chip flow by reducing the friction coefficient and the cutting forces ((Ti, AI)N: hard layer (3300 HV), WC/C: lubricant layer of medium micro-hardness and low friction coefficient (1000 HV)) [5].

This coating is used when to machine sott steels and aluminium alloys.

Diamond: When machining aluminium alloys without any coolant, we need high wear-resistant cutting tools because the intermetallic particles inside the aluminium matrix uickly wear the tools; diamond coating is one of the solutions to these problems. Recently, chemical vapour deposition (CVD) diamond coatings have been used for cutting tools in various cutting conditions [8]. Diamond is very hard (10, 000 HV) and presents a high wear resistance.

In order to evaluate the influence of the drill material coating on the holes quality, several tests were carried out in this work with the tool geometries presented in Table 1 (see TF-type tools). In the current analysis, the hole quality produced by the uncoated drill A is compared to the one obtained with the coated tools B ((Ti, Al)N coating), C (coating) and D (diamond coating). The uncoated drill A offers a better roughness compared to drills B-D (Fig.

2a). This performance may be due to the small value of the feed rate (f = 0. 04 rev/min).

Indeed, with low feed rate values, the cutting forces and the tool-chip interface temperature are not very high. Therefore, the hole quality is not much affected when machining with the uncoated drill A.

For the diamond coated drill (tool D), the results are better when the minimum diameter deviation is considered as a quality criteria for cutting velocity V = 165 m/min, see Fig. 2d (only one cutting elocity is used for this coating). It is interesting to note that the (Ti, Al)N coated drill offers a very poor tolerance except for the maximum diameter deviation (Fig. c). To conclude, we can say that coatings do not really improve the machining quality but the diamond and (T’, Al)N + WC/C coated tools produce a quality which is very close to that of the uncoated tools.

3. Optimisation of dry drilling 3. 1. Optimisation procedure A detailed statistical analysis (analysis of variance) established from the experimental results was used to optimise the value of the parameters affecting the hole

quality helix angle, point angle, lip relief angle, web thickness, lips number, margin width).

It allowed to study the contribution of each parameter, and to find a compromise between the different criteria (roughness, maximum and minimum diameter deviation, burr height).

An optimised drill was made in order to have a high surface quality while preserving an average height of the burr lower than 20 0m, an average minimum diameter deviation ranging from O 0m to 10 0m and an average maximum diameter deviation between 15 0m and 25 0m. These criteria are those usually found in aerospace industry. The shape of the ptimised drill and the geometrical parameters cannot be revealed in this paper because of the confidentiality.

However, the general tendencies for the most significant parameters are as follows: it is preferable to have a high helix angle, a sufficiently large point angle, a low margin width, a lip reliet angle betw 80 , and a rather low web thickness. 3.

2. Tests with optimised drills According to the previous conclusions, we carried out prototype carbide drills with 6 mm of diameter without any coating. The optimised drills were tested in a large range of cutting conditions; cutting speeds between 19 m/min nd 283 m/min and feed rate between 0. 04 mm/rev and een 6 0. mm/rev were considered. The results that were obtained after 500 holes, are illustrated in Fig.

3. The holes quality is evaluated in terms of the average roughness the maximum dmax and the minimum dmin diameter deviations. For a fixed feed rate value, we observe (Fig. 3a) the existence of an optimal velocity (Vopt = 170 m/min for f = 0. 16 mm/rev), for which the average roughness, the maximum and minimum diameter deviations produce a high holes surface quality (Ra < 1 0m, dmax < 15 and dmin < 5 0m).

Beyond Vopt , it appears that Ra , dmax and min increase with the cutting speed V.

In other words, the combination of large cutting speed and slightly weak feed rate gives a bad surface quality of the produced holes. It can also be noticed that the roughness increases according to the feed rate. The results emphasize the existence of a compromise between the parameters that have an important influence on the holes quality. In Section 2.

2. 1, the optimal speed of the non- optimised drills (producing holes with a feed rate of 0. 04 mm, see Fig. 2) is about 65 m/min. With the optimised tool, this velocity was increased (Vopt = 170 m/min).

In the case of dry machining, the tool-chip emperature plays a major role in determining the hole quality. However, the larger is the cutting velocity the shorter is the contact time between the tool and the hole surface. So, the heat that was produced in the tool-chip contact does not have enough time to affect the surface quality and the dimensional accuracy of the holes. 4. Tool wear The heat produced during the dry machining process is critical in terms of tool life and workpiece surface quality.

1363 Fig. 3. Influence of cutting conditions for the optimised drill for 500 holes.

Inspite ot the large amount ot data and knowledge which as been accumulated, tool wear is still not fully understood. Several basic causes of tool wear have been investigated; the most important are: abrasion, adhesion and diffusion [1 2, 13].

The magnitude of the tool-chip interface temperature causes shift from abrasion to adhesion, or from adhesion to the diffusion wear process. ature can be measured; nevertheless, it is also important to determine temperature distribution by numerical means, so as to be able to develop predictive models. The finite element analysis code Third Wave AdvantEdgeTM is used in the present paper.

This Lagrangian code employs ynamic effect and coupled transient heat transfer analysis. The friction law is based on a Coulomb law [1 5]; the FEM code uses a power strain-hardening law including the strain rate effect: