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A Parametric Model for the Straightness Deviation in the Cutting Processes of Aluminum Alloys

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Abstract. Light alloys are increasingly applied in different industrial sectors, mainly aerospace. Because of this, it is needed to analyze their behavior in the different processing procedures and, specially, machining. On the other hand, up to a few years, cutting fluids were successfully employed in these processes since their coolant and lubricant properties. Notwithstanding, environmental necessities have promoted researches focused on the development of cleaner processes avoiding cutting fluids, in particular, dry machining. However, this process can change tool geometry and affect to the material giving rise to changes in the design specifications. In this work, geometrical deviations, particularly straightness deviations, in the dry turning of UNS A92024 (Al-Cu) alloy are studied as a function of feed and cutting speed through a parametric model.

Keywords: Aluminum alloys, UNS A92024, Turning, Straightness Deviation, Parametric Model

Introduction

Applications of light alloys are continuously increasing in industry thanks to, fundamentally, two causes. First of them, the improvement in these alloys development; secondly, their excellent relationships cost-weight-physicochemical properties. In particular, aluminum alloys have been increasingly applied in different industrial sectors, mainly aerospace. In this context, aluminum-copper and aluminum-zinc alloys have been widely employed for manufacturing a lot of structural airship components.

Because of this, in the last years, intense research efforts have been achieved in order to analyze their behavior in the different materials processing procedures.

Among of them, and due to the assembly requirements, machining has been one of the processes more deeply studied. In this kind of processes, cutting fluids are commonly applied in order to, on the one hand, act as a coolant over the tool and, as a consequence of this, try to avoid or, at least minimize, the undesirable and pernicious effects provoked by the high cutting temperatures reached

during the cutting processes. On the other hand, these fluids acts as lubricants. This fact supposes a decreasing of friction in the tool-material cutting zone, making easy the chip flow and, thus, giving rise to a decrease of the frictional tool wear. Nevertheless, environmental laws have driven the production systems toward the application of cleaner technologies minimizing the application of these fluids. In this way, cutting processes using minimum quantity of lubricant (MQL) or, better, dry machining technologies, have been promoted as low environmental impact alternatives to classical machining processes which use those cutting fluids [1-5].
This work reports on a part of the results of different Research Projects between AIRBUS Spain, S.L., EADS-CASA, the Materials Technology Research Group of the University of Cadiz, Spain, and the Manufacturing Engineering Research Group of the Spanish University of Distance-Learning, placed in Madrid, Spain. These projects look for the optimization of machining processes of different alloys commonly used in the aerospace industry on the basis of environmentally-friendly considerations. In particular, in this work, straightness deviation (SD) produced in the dry turning of UNS A92024 Al-Cu alloy has been studied for different cutting speeds (v) and feeds (f) values. The results obtained allowed establishing a parametric model for predicting this geometrical deviation as a function of those parameters.

Experimental Procedure

The workpieces used in the experimental tests carried out in this work were cylindrical bars (150 to 200 mm long with diameters between 80 and 120 mm) of UNS A92024 alloys. The composition of this alloy was analysed by ICP. Table 1 contains the mass percentage of the main elements in it.

Table 1. Nominal Composition of UNS A92024 alloy (% mass)

Cu	Mg	Mn	Si	Fe	Zn	Ti	Cr	Al
4.00	1.50	0.60	0.50	0.50	0.25	0.15	0.10	Rest

The cylindrical bars of alloy UNS A92024 were horizontally dry turned in an EmcoTurn-242 CNC Lathe equipped with an Emcotronic TM02 Numerical Control, Figure 1. Cutting speeds from 40 up to 170 m/min, and feeds from 0.05 up to 0.3 mm/rev were applied. All the combinations between the values of these parameters were achieved. Cutting depth was maintained at 2 mm in all the experiments.

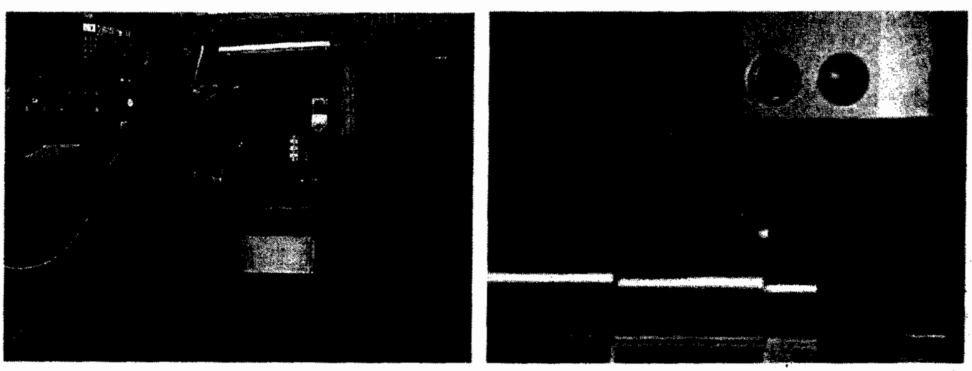

Fig. 1. CNC Lathe and a frame of a clip acquired during a turning test.

The tools employed were TiN covered WC-Co turning inserts with ISO KCMW 11T3 08 FN M-identification. The cutting process was monitored by using a NIKON 4500 Coolpix Digital Camera. Straightness deviation (SD) was measured through a comparer clock magnetically placed in the lathe revolver in order to draw four horizontal lines where the measurement was achieved, as it can be observed in Fig. 2.
Thirty SD points were acquired in each line. For each pair of parameters, v and f, SD value was assumed as the average deviation obtained in the four lines.

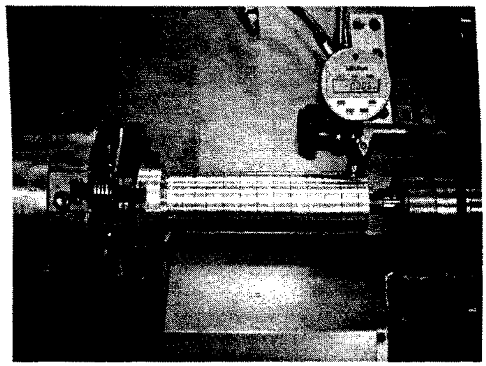

Fig. 2. Experimental straightness deviation points acquisition device

Results and Discussion

Fig. 3(a) plots the evolution of the straightness deviation (SD) calculated average values as a function of the cutting speed for the different values of feed. In the same way, Fig. 3(b) plots the evolution of the straightness deviation (SD) calculated average values as a function of the feed for the different values of cutting speed.
In these figures, SD shows a tendency to increase when both feed increases and cutting speed decreases. In this way, it can be observed a certain convergence of SD values for the highest cutting speed values and the lowest feed values. On the other hand, a dispersion of values can be appreciated for the highest feed values and the lowest cutting speed values.
These results can be related with the observations about the chip arrangement found in [6]. In effect, in agreement with those observations, when highest feeds and lowest cutting speeds are applied, shortest chips are obtained. According to [7], this fact provokes interruptions in the tool-chip contact, giving rise to deviation in the machining path.
Additionally, in these conditions, a higher instability of BUE developed in these kind of processes can be detected. This fact brings on a higher alteration in the continuity of the cutting process [3-5].
Therefore, high speed and low feed dry turning processes of UNS A92024 allows a better approximation to geometrical specifications, at least, in the straightness field.
On the other hand, it can be found a high degree of coherence among the appreciations made in [6] about the process, the chip, the workpiece and the tool and results that have been obtained in the SD measurements.
Thus, coming back to Fig. 3, the exposed results suggest the possibility of looking for a parametric model for expressing SD as a function of v and f.

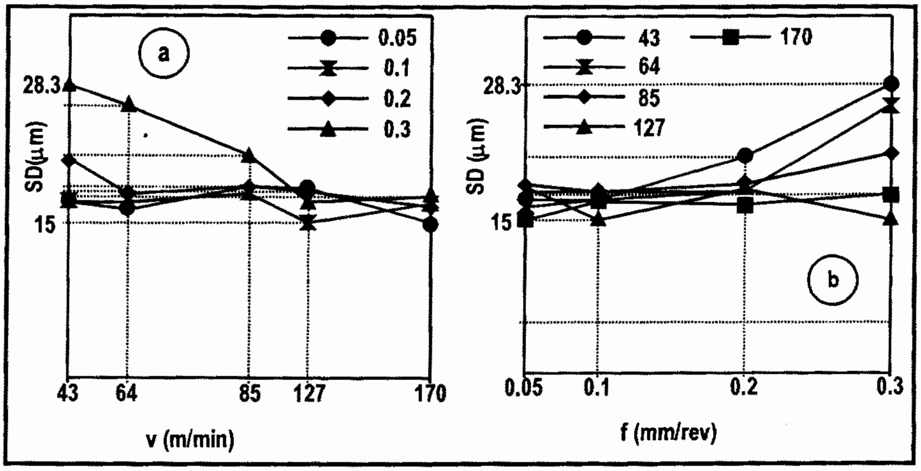

Fig. 3. Straightness deviation evolution as a function of (a) cutting speed for the indicated feed values; (b) feed for the indicated cutting speed values.

Usually, parametric models relating cutting variables with cutting parameters are *Tayloristics Models* having a potential form [6,8,9]. In this case, the adjustment of the experimental data to potential equations showed a very low correlation coefficient, giving to think that alternative forms had to be investigated for the parametric model.
Different mathematical forms were tested for this variable. Attending to the points placement in Fig. 3, an exponential model can be suggested. Thus, a model as the following was tested:

$$SD = C \cdot e^{\sum_{i=1}^{2}\sum_{j=1}^{2} k_{ij} \cdot f^{i} \cdot v^{yj}} \qquad (1)$$

This equation can be written as follows:

$$\text{Ln}\,[SD] = \text{Ln}\,C + k_{11} \cdot f \cdot v^{y} + k_{12} \cdot f \cdot v^{2y} + k_{21} \cdot f^{2} \cdot v^{y} + k_{22} \cdot f^{2} \cdot v^{2y} \qquad (2)$$

The values of the coefficient and exponents of Eq. 2 can be calculated by using techniques of non linear regression following a step by step regression procedure. This methodology allows eliminating no significant contributions of the variables and/or parameters with a minimal lost of he adjustment quality.
Step by step regression procedure was carried out in its two different ways: incorporating a variable in each step and making the adjustment with the more relevant variables; or eliminating a variable in each step. In this study, both adjustment ways has given similar results (confidence interval of 95%). Thus, as it is referred in [6], the model with the lowest number of variables or parameters is the selected.

The coefficients and exponents obtained by this method have been:

$C = 16.475$

$k_{11} = k_{12} = 0.000$

$k_{21} = -33.992$

$k_{22} = 142.740$

$y = -\ 0.270$

Thus, the model recorded in Eq. 2 can be written as:

$$SD = 16.475 \cdot e^{(-33.99 \cdot a^2 \cdot v^{-0.27} + 142.74 \cdot a^2 \cdot v^{-0.54})} \qquad (3)$$

As it can be deduced from Eq. 3, straightness deviation is specially modulated by the values of feed, changing more slowly with cutting speed, as it was previously commented.
Starting from the parametric model of Eq. 3, predictive values of SD can be found for feed and cutting speed values out of the range of the values employed in the dry turning tests.
Differences between experimental and theoretical data were no higher that 10%. Thus, the proposed model can be accepted.

Conclusions

In the machining processes of aluminum alloys, interactions and interferences in the tool-workpiece system can cause dimensional and geometrical deviations respect the specification initially defined by design.
The tool-workpiece interactions can be amplified when the cutting process is carried out in absence of cutting fluids in order to minimize the environmental and toxicological impact of this kind of fluids.
In this paper, the straightness deviation (SD) measured in horizontally deep constant dry turning processes carried out on bars of UNS A92024 aluminum-copper alloy has been analyzed as a function of feed and cutting speed.
According to the data obtained in the dry turning tests, the increase of the cutting speed and the decrease of the feed can provoke a loss of precision in the straightness of the dry machined workpieces.
In the opposite way, a convergence of the lowest values of the straightness deviation has be found for the lowest values of the cutting speed and the highest values of feed.
These findings have been related with the chip both formation and arrangement, according with other results previously obtained.
On the other hand, SD values acquired experimentally have allowed establishing a parametric model for this variable as a function of the two cutting parameters employed. This model is not a

potential model like those previously obtained for other quality finish parameters, such as average roughness.
According to that model, the straightness deviation is stronger controlled by feed in a inverse form, causing the higher variations in this variable. On the other hand, SD is moderately modulated by cutting speed values.

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