The Study of an Exponential Parametric Model for Evaluating Parallelism Deviation of Aerospace Alloys during Turning

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Abstract: Aeronautical industrial sector applies currently aluminium alloys in a wide range of its products. Aerospace precision requirements are highly restricted. Thus, dimensional precision is commonly studied in the manufacturing processes of aerospace alloys, such aluminium. As a consequence of this, quality finish of machined aluminium alloys for aeronautical use is deeply analysed, although mainly in terms of dimensional accuracy. Geometrical precision is usually studied from roughness analysis, which only has into account microgeometrical aspects. However, macrogeometrical precision is commonly far of the objectives in some of those analyses. In this work, Parallelism Deviations (PD) of dry turned UNS A92024 (Al-Cu) and UNS A97050 (Al-Zn) samples have been evaluated for different machining conditions (cutting speeds and feeds). A parametric model for the parallelism deviation as a function of those cutting parameters has been established from the mathematical treatment of the results obtained. In parallel, a prediction surface PD (f, v) has been constructed from the 3D interpolation of the set of (f, v, PD) points. This surface allows determining marginal PD (f) and PD (v) curves for specific v and f values, respectively.

Keywords: Dry turning, parallelism deviation, UNS A92024, UNS A97050

INTRODUCTION

Aluminium alloys are widely employed in airships building industry because of their excellent ratio weight-density/mechanical properties/cost. Thus, most of principal airship structural parts are formed by aluminium alloys, mainly aluminium-copper alloys such as UNS A92024 and aluminium-zinc alloys such as UNS A97075, UNS A97050 and UNS A97475. These alloys need to be mechanically worked by different machining processes due to necessities of manufacture and assembly. Each element of an airship and among them, the machined aluminium alloys pieces, requires a high level of surface quality. Thereby, dimensional and geometrical design specifications must be rigorously followed. In this sense, a great number of papers related to the study of surface finish quality of aluminium machined workpieces can be found in literature (Sebastian *et al*., 2003; Rubio *et al*., 2004; Sánchez-Sola, 2004). Notwithstanding, these studies are fundamentally focused on the analysis of dimensional parameters, mainly roughness parameters, such as Ra or Rz. However, there is a lack of research works about the study of the surface quality under the point of view of geometrical deviation parameters.

Summarising, in this work, Parallelism Deviation (PD) of dry turned UNS A92024 (Al-Cu) and UNS A97050 (Al-Zn) cylindrical bars have been studied in a

Table 1: Cutting parameters

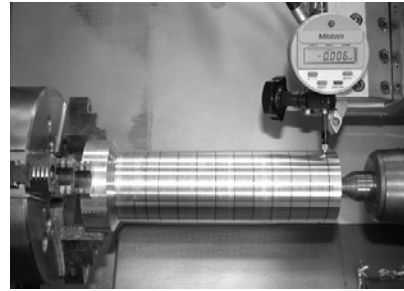| Vc [m/min]	43	65	85	125	170
f [mm/rev]	0.05	0.10	0.3		

Fig. 1: Experimental device employed for measuring the parallelism deviation in the CNC Lathe

wide range of cutting speeds (v) and feeds (f). The results obtained have allowed establishing a parametric model for predicting the parallelism deviation as a function of those cutting parameters.

In parallel, a geometrical surface PD (f, v) has been constructed for each alloy. This surfaces allows determining marginal PD (f) and PD (v) curves for specific v and f values, respectively, out the parameter ranges employed. So, a parallelism deviation can be predicted through this model for v and f values out of those considered in the study for each alloys.

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EXPERIMENTAL

The workpieces used in the experiments were cylindrical bars of UNS A97050 (Al-Zn) and UNS A92024 (Al-Cu) alloys. These workpieces were horizontally dry turned in an EmcoTurn-242 CNC lathe. Cutting speeds and feeds are shown in Table 1. All the combinations between the values of these parameters were achieved, maintaining a fixed depth of cut (A_p=2 mm) and using TiN covered WC-Co cutting tools (ISO KCMW-11T3-08-FN-M reference, from SECO). Figure 1 shows the experimental device employed for measuring the parallelism deviation in the CNC Lathe. As it can be observed, a comparer clock was magnetically placed in the lathe revolver in order to draw the four horizontal lines, separated 90º, where the measurement was achieved.

Parallelism deviation points were acquired each 5 mm in each line. Points were mathematically treated in order to obtain average values in the four lines. Finally,

(a)

(b)

Fig. 2: Evolution of the average values of PD as a function of, (a) cutting speed for the different feeds applied and, (b) feeds for the different cutting speeds applied

Parallelism Deviation (PD) was defined as the difference between the maximum and minimum values of the registered points. Parallelism deviation limits is considered defined by two lines which are parallel to rotation axis and which contains those extreme points.

RESULTS AND DISCUSSION

For each pair of values (f, v) the PD value considered has been the average value of the four PD values recorded. Figure 2 plots the evolution of the average values of PD as a function of cutting speed for the different cutting speeds and feeds applied, in both alloys.

As it can be observed in Fig. 2a, there is a similar trend in the PD (v) for each feed applied in both alloys. In effect, a soft decrease of PD with the cutting speed can be appreciated. According to that concluded in previous works, it can be caused by the evolution of the changes in the tool geometry as a consequence of the Built-Up Edge and Built-Up Layer formation (Sebastian *et al.*, 2003). Notwithstanding, it must be taken into account that the maximum values for each cutting speed is reached when highest feed is applied. This is in good agreement with conclusions reached in previous works about the relationship between surface finishing quality and feed (Sebastian *et al.*, 2003; Sanchez-Sola *et al.*, 2004).
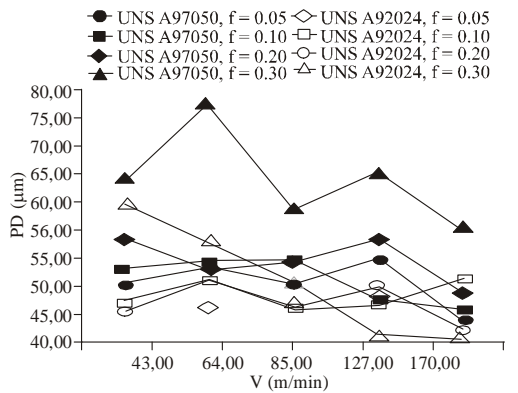
On the other hand, for a cutting speed, parallelism deviation increases highly with the feed from a critical value. This fact can be more clearly appreciated in Fig. 2b. As it can be observed, parallelism deviation is almost constant for feed values between 0.05 and 0.2. For higher values, PD records increase highly. This observation is according to those related with the chip formation and the adhesion effects (Sebastian *et al.*, 2003).

Starting from all these values it is possible to propose a mathematical model as relationship between PD and the cutting parameters feed (f) and cutting speed (v) for each alloy.
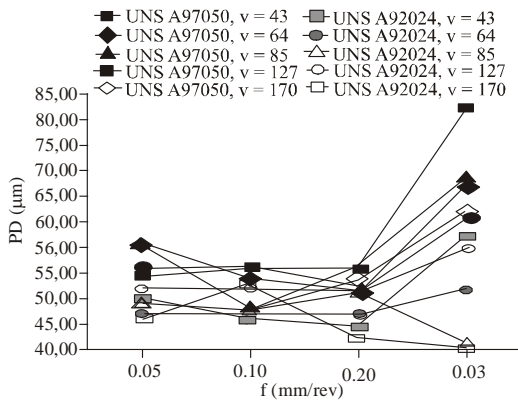
Classical parametric models for establishing relationships between finishing quality variables (Ra, Rz,…) and cutting parameters (f, v, p) are usually potential models. In this case the first parametric model tested was, effectively, a potential model. However, very bad results were obtained and the theoretical values calculated were too far of the empiric values obtained.

Because of that, alternative models have been tested. The best behaviour has been reached for an exponential model as (1):

$$PD = C.e^{\sum_{i=1}^{2}\sum_{j=1}^{2} K_{ij}.f^{i}.v^{yj}} \tag{1}$$

Table 2: Multilinear regressions values for each alloy

	C	y	K_{11}	K_{12}	K_{21}	K_{22}
UNS A92024	48.40	- 0.08	14.38	- 21.26	-119.88	174.13
UNS A97050	62.10	0.60	- 0.22	0.00	1.00	- 0.01

Table 3: Standard deviation of residuals and absolute average error for both models

	UNS A97050	USN A92024
Standard deviation of residuals	0.073	0.053
Absolute average error	0.052	0.038

For determining the values of the coefficients, a linear regression procedure has been followed over the linear form of Eq. (1), written in a logarithmic scale as (2).

$$In\ (PD) = InC + \sum_{i=1}^{2} \sum_{j=1}^{2} K_{ij} \cdot f^{\,i} \cdot v^{\,yj} \qquad (2)$$

Multilinear regressions for each alloy reported the values included in Table 2.

From these values, the PD (f, v) parametric model can be constructed by substituting them in (1) for each alloy as follows:

$$PD_{UNS\ A97050} = 62.10$$
$$e^{-0.22\,fv^{0.60}+1.01f^{2}v^{0.60}-0.0f^{2}v^{1.20}} \qquad (3)$$

$$PD_{UNS\ A92024} = 48.40e^{14.38\,fv^{-0.08}} - 21.26f\,v^{-0.16}$$
$$- 119.88f^{2}v^{-0.08} + 174.13f^{2}v^{-0.16} \qquad (4)$$

When both models are compared, it can be noticed that C coefficient is higher (30%) for UNS A97050. This is in good agreement with the observed in Fig. 2. On the other hand, feed influence is highly less accused in the case of that alloy, in good agreement with that included in (1). In effect, Zn presence in the alloy increases its plasticity forming a more continuous chip at any feed that influences negatively in the finish quality of the dry turned pieces. Moreover, this sensibility is strongly dependent of the cutting speed (positive exponent in the exponential polynomial).

Simulated PD (f, v) values showed a good approximation (higher that 95%) to those experimentally measured for v and f values included into the range studied for each Al alloy. Table 3 shows the standard deviation of residuals and absolute average error for both models.

Additionally, parametric models like those included in Eq. (3) and (4), give rise to parametric surfaces PD (f, v) for each alloy. Each point of these surfaces can serve to predict the PD value out of the range of values employed for feed and cutting speed. In parallel, a geometrical construction of predicting PD (f, v) surfaces
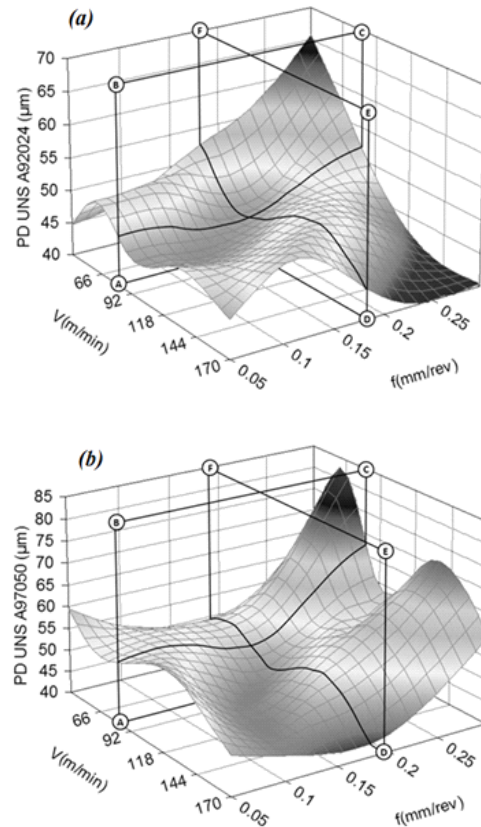

Fig. 3: Parametric surface PD(f,v) for (a) UNS A92024 and (b) UNS A97050

can be made by considering two Bezier curve families for generating a Coons surface, Fig. 3.

An experimental validation of the predictive method for determining the parallelism deviation was achieved by comparing new experimental values with predicted values coming from the surface. These predicted values are determined by intersecting two orthogonal PD-f and PD-v planes. So, as it is shown in Fig. 3a, plane ABC (PD-f) is defined for a specific cutting speed (in this case 82 m/min). The intersection of this plane with the PD surface defines a PD (f) marginal Bezier curve for that cutting speed. In the same way, plane DEF (PD-v) is defined for a specific feed (in this case 0.18 mm/rev). Now, the intersection of this plane with the PD surface defines a PD (v) marginal Bezier curve for that feed. Both curves have a common (intersection) point, which correspond with the predicted value of PD (82, 0.18). The experimental PD result obtained for these v and f values was lower that 5% deviated from the predicted and both keep a good correspondence with the evaluated through the exponential parametrical model.

On the other hand, in the Fig. 3b for UNS A97050, marginal Bezier curves has been determined from the intersection of the predicting Coons surface with plane

PD-f for v = 82 m/min and plane PD-v for f = 0.19 mm/rev. Predicted values obtained by using the different methods has shown again a good approximation to the experimental measurements (approximation higher that 95%).

CONCLUSION

Parallelism deviation (PD) has been studied as a function of cutting speed for each feed applied as well as a function of feed for each cutting speed applied in the dry turning of UNS A92024 and UNS A97050 alloys. Results obtained have shown that higher values of PD are obtained for lowest speeds and highest feeds. These results can be related with both chip arrangement and adhered material forms in either tool edge or tool rake face.

Marginal PD (v) and PD (f) relationships allow considering the establishment of a PD (f, v) parametric model. The best adjustment has been reached for an exponential model as that included in Eq. (3) and (4) for both alloys.

Additionally, parametric surfaces PD (f, v) can be adjusted to the experimental data through Coons interpolations. Each point of these surfaces can serve to predict the PD value out of the range of values employed for feed and cutting speed. These predicted values are comparable with those calculated from the exponential models.

Therefore, results obtained have shown that there is a good correlation between experimental and simulated values of the parallelism deviation.

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