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Comparison between analytical and experimental roughness values of components created by incremental forming

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ABSTRACT

In the following work, a comparison is made between the analytical and the experimental values of the surface roughness of components created by incremental forming, a highly flexible innovative sheet metal forming process.

This work provides a previous description of a predictional model for the evaluation of two parameters of amplitude and one of spacing of the surface roughness; taking geometrical considerations as a starting point, these parameters are described depending on the tool radius, the vertical step and the slope angle of components created by incremental forming.

An experimental campaign is then carried out, creating components with the shape of pyramid frusta; the tests, which take sheets of an aluminum alloy widely used in forming processes and for reasonable values of the key parameters, provide useful information to highlight the differences between the predictional model previously described and the effective values of the surface roughness.

1. Introduction

Incremental forming is one of the most versatile sheet metal forming technologies, not counting the use of dies. The geometric precision is, of course, one of the main targets for industrial researches. This aspect has been treated both in macroscopic and microscopic terms in the past.

Relatively to studies on the geometrical accuracy in microscopic terms, Hagan and Jeswiet (2004) highlighted the importance of the roughness, especially for automotive parts. In their studies, they described the surface finishing in incremental forming as a combination of large-scale waviness resulting from the tool path and small-scale roughness resulting from large surface strains; it was shown that, as the vertical tool step decreases, the surfaces are seen to transform from wavy to strictly roughness without waviness. Furthermore, the tool rotation speed does not influence the roughness.

Surface roughness, that presents mean values of 4–12 μm for sheet metal forming processes, in incremental forming is regarded as a weak point compared to the traditional processes; consequently, the possibility to predict the surface roughness values in incremental forming can result useful, in order to control this important target.

A model for evaluating the roughness, both in terms of amplitude and spacing, was described depending on three parameters: the slope angle, the vertical step and the tool radius; as far as the influence of these parameters is concerned, Junk et al. (2003) observed an increase of roughness with the vertical step and a decrease with the diameter and the slope angle.

As amplitude parameters, the average roughness [R_a] and a parameter of max roughness [R_z] were analyzed; these two parameters were chosen because R_a is widely used as a parameter for the surface finishing, while R_z rather than R_t was chosen to prevent any accidental surface irregularity from influencing the experimental evaluation of the roughness. In fact, whereas R_t represents the maximum height of the profile, R_z is the average of this feature, evaluated on ten points. *RSM*, that is the mean spacing between profile peaks, was chosen as spacing parameter.

After the analytical treatment, an experimental campaign was conducted on sheets of AA7075 T0, an aluminum alloy used in the field of aerospace for structural applications. The results of the experimental campaign were analyzed, in order to keep conclusions related to the influence of the above-mentioned parameters, and finally compared with those from the analytical model previously described, in order to highlight the differences between the analytical model and the experimental data.

2. Theoretical evaluation of the roughness

The aim of this section was an analytical prediction of the surface roughness of the components created by the incremental forming

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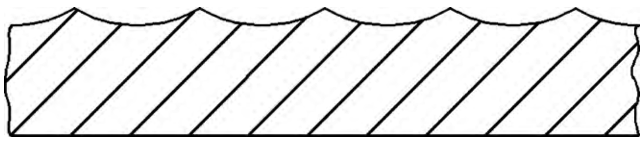

Fig. 1. Roughness profile for the predictional model.

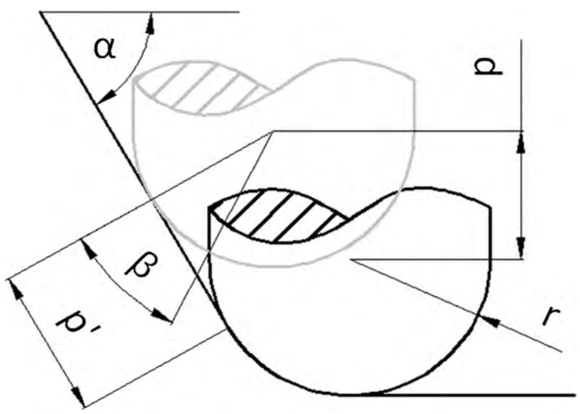

Fig. 2. Characteristic features of the roughness profile model.

process on varying the process parameters and the geometry of the components. A previous model was described under the hypothesis of deformation that follows the tool path completely; considering a transverse section of the component to be created, the description of a regular roughness profile provided by the envelope of subsequent tool positions can be assumed, as is shown by the section perpendicular to the direction of tool movement, of the formed sheet in Fig. 1.

In order to evaluate the characteristic features of this profile, it is necessary to describe the following features, represented in Fig. 2 (two subsequent passes of the tool over the same tangential location are pictured in grey and in black):

$$p' = \frac{p}{\sin a} \tag{1}$$

$$\beta = \arcsin\left(\frac{p'}{2r}\right) \tag{2}$$

where α is the slope angle of the components; p is the vertical step of the tool path; r is the tool radius.

It is clear that the above-mentioned roughness profile model implies dependence of the roughness on the process parameters p and r and the geometrical parameter α.

On the basis of the previous considerations, analytical models to describe RSM, R_a and R_z were investigated. Obviously, R_z and R_t proved to be equal for the theoretical model, as accidental surface irregularities were not expected; moreover, as far as the spacing parameter is concerned, it is valid that:

$$RSM = p' \tag{3}$$

As regards the two amplitude parameters, when limited to a semi-wave of the hypothesized roughness profile, expressed depending on the vertical step (Fig. 3a), these can be formulated by the following equations:

$$R_z = y\left(x = \frac{p'}{2}\right) \tag{4}$$

$$R_a = \frac{\int_0^{p'/2} |y(x) - y|dx}{p'/2} \tag{5}$$

A geometrical treatment for the evaluation of the parameters expressed by (4) and (5) was carried out. R_z, as can be easily observed in Fig. 3b, can be expressed by:

$$R_z = r(1 - \cos\beta) \tag{6}$$

For the evaluation of R_a, $\bar{y}$ was evaluated first, that is the average height of the roughness profile. This one was evaluated making the areas labeled 1 and 2 in Fig. 3c equal. The geometrical treatment led to the evaluation of $\bar{y}$ as equal to:

$$\bar{y} = R_z - \frac{r^2\bar{\beta}}{p'} + \left(\frac{r\cos\bar{\beta}}{2}\right) \tag{7}$$

with $\bar{\beta}$ equal to:

$$\bar{\beta} = \arccos\left(1 - \frac{\bar{y}}{r}\right) \tag{8}$$

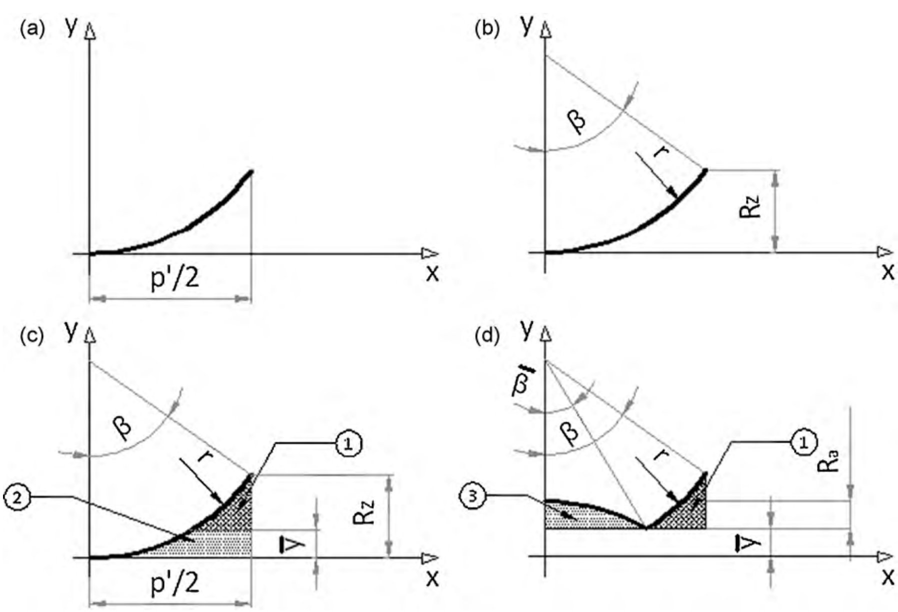

Fig. 3. Geometrical features for the evaluation of the predictional model.