Considerations on the Incremental Forming of Deep Geometries

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ABSTRACT: New research trends on Incremental Forming processes are strongly based on the development of more efficient control tools or design procedures, able to reduce the time associated to the preliminary set-up phase. The latter, in fact, still penalises the industrial application of the above process. If adequate knowledge has been reached nowadays, thanks to the activity of several researchers all over the World, the process feasibility of complex or irregular geometries is still related to the execution of some preliminary "trial & errors" experimental tests. It seems quite obvious that more efforts have to be spent to increase the process control capability by means of innovative and generalised solutions, such as artificial intelligence techniques, neural networks, numerical simulations and so on. With this perspective, the present paper aims to improve the IF control capability for complex shapes by means of an optimised FE model.

Keywords: Incremental Forming, Material Behaviour, Numerical Simulations.

1 INTRODUCTION

Although Incremental Sheet Forming of industrial parts is not very common, a number of studies were carried out in order to overcame some specific problems [1]. At the same time, the capability to obtain a very high material thinning as compared to any traditional sheet metal forming process and the possibility to use a very cheap equipment suggest to improve the knowledge and the development of Incremental Forming technique. One of the most investigated aspects concerns the material formability and, in particular, the maximum slope angle allowable by the forming material and the process parameters. However, a simple approach based on the sin law, according to spinning, is not completely convincing since material thinning follows a more complex behaviour.
In this context the importance of a prediction model or a numerical simulation, to evaluate the thickness distribution is of course a key-factor. Moreover, in the last years, the finite element analysis showed its potentiality as predicting tool in manufacturing processes. In particular the introduction of the explicit approach represented an important innovation to investigate the sheet metal forming processes. Many works were carried out to show the robustness and the reliability of the numerical results, but nowadays this has to be assessed for the Incremental Forming Processes, specially when complex shapes are investigated. The last ones, in fact, are characterised by a different mechanical behaviour, then the absence of a very robust law, able to define the deformation behaviour, increases the difficulties in the process design. For these reasons the application of a FE model could represent a strategic tool for the process development.
Up to now, several study were focused on the FEM analysis, taking into account simple shapes [2, 3]. In the present paper the robustness of the numerical results was tested simulating the IF operation for more complex geometries, characterised by a variable wall inclination angle, and contemporary compared with experimental ones. An experimental campaign was firstly executed to validate the FEM capability in thinning prediction for complex shapes. A good overlapping between experimental and numerical data was found out.
All the details will be explained in the paper.

2 FORMABILITY ANALYSIS

The material formability and the full understanding of the process mechanics are still an open point in the ISF research. Many improvements have been already introduced in the process knowledge, from both a fundamental research point of view and the implementation of simple laws suitable for industrial users. From the literature review [4, 5], initially, the process formability was simply classified by means of two parameters:

- the FLD_0 point, which corresponds to the intersection between the major strain axis and the FLC;
- the α_{max}, which represent the maximum slope angle of the wall, that can be safely manufactured.

Unfortunately, due to the process complexity, some drawbacks can be recognized with this indexes: first of all, both the FLD_0 and the α_{max} values directly depend on the adopted process parameters, so that they can not synthetically describe the whole process; secondly, although the α_{max} is easier to be used from an industrial point of view, at the same time it supplies only a partial knowledge on the process feasibility. Some applications, in fact, showed that slope angles, higher than the critical one, can be safely obtained specially when complex geometry, characterized by a variable slope wall, has to be manufactured [6]. The latter, for instance, are usually characterized by different slopes, sometimes higher than the critical one, with a depth associated to each slope usually low. According to that, it was shown [7] that a correlation between the critical slope angle (α_{max}) and the workpiece depth (H_f) exists for given material and process parameters. In other words, when the critical angle is adopted, it is reasonable to think that material damage occurs only after a given depth. In this direction, an analytical law was statistically derived by the authors, aimed to predict the maximum allowed depth for fixed process parameters and wall inclination angle. Even if the model suitability was firstly statistical evaluated by using performance indexes and, then, experimentally validated with respect to new geometrical configurations, it was based on a single slope geometry. On the contrary, its extension to more general multi-slope shapes would require the execution of a exponential number of tests.

Starting by these results a new investigation was firstly executed and then numerically evaluated.

3 EXPERIMENTAL CAMPAIGN

With the aim to well asses how formability limit changes increasing the product complexity, a more general experimental campaign was designed. It is quite obvious that introducing new degrees of freedom in the geometry the problem complexity proportionally increases. Actually, the analysis complexity increases since the maximum reachable height is not only influenced by the process parameters or the material properties. On the contrary, the transverse section changes and the partial slopes of the wall angle play a relevant role on the final results. With this perspective, the prediction of the maximum formability for a multi-slope geometry could become NP-hard problem, since higher number of factors increase the problem dimension, thus increasing the solution times.

Here, for sake of simplicity, some factors were fixed or neglected. To do that, firstly, it was decided to keep constant the process parameters during the whole experimental campaign; more in detail:

- Punch diameter (D_p) was fixed equal to 12 mm;
- Tool depth step (p) was fixed equal to 1 mm;
- Sheet thickness (s) equal to1 mm was utilised.

Contemporary, an aluminium alloy AA 1050-O was used for the experimental campaign, in order to manufacture a frustum of cone, characterised by a double curvature along the transverse section. According to the major base diameter (D_0), the maximum design height to reach (H_f) was fixed equal to 70 mm, defining a sort of cubic working space. Vice versa, two different slopes were imposed, respectively the former H_1=20 mm and the latter H_2=50 mm (Figure 1).

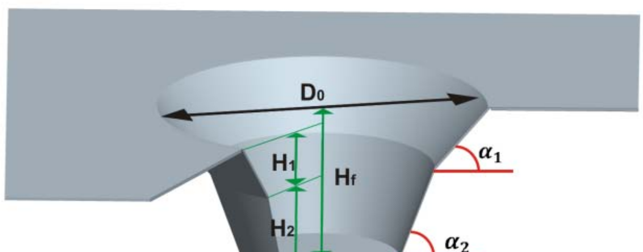

Fig. 1. Sketch of the manufactured geometry.

In order to explore the critical region of the research space, both safe and unsafe wall inclination angle were taken into account for α_1 and α_2 values, as shown in the next table 1.

Of course the cases in which α_1 and α_2 coincide the geometry results in a simple conical shape.

Table1. Investigated wall inclination angles

Input parameters	
α_1	[65° – 70° – 75°]
α_2	[65° – 70° – 75°]

An orthogonal experimental plane was executed, with three repetitions for each angles combination.
A circular baking plate was used to sustain the blank during the punch movement, and five millimetres of gap were always left between the first loop of the trajectory and the baking plate.
In figures 2 and 3, two experimental results are proposed to represent both process success and failure.

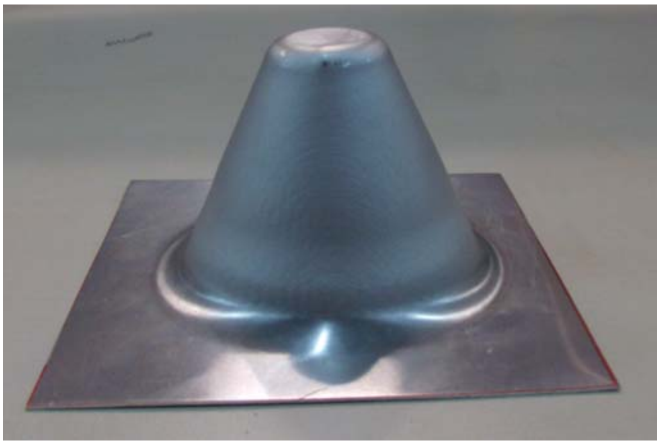

Fig. 2. Sound component obtained with α_1= 65° and α_2=70°.

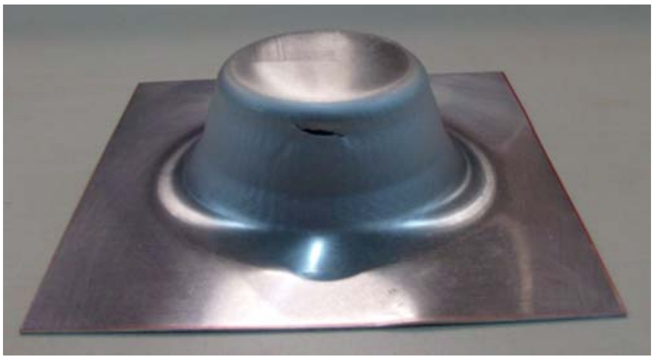

Fig. 3. Broken component obtained α_1=65° and α_2= 75°.

Beside ISF is strongly characterised by a localised process mechanics, so that the general idea is that only the portion of material in contact with the punch undergoes to plastic deformation, the experimental results suggested that it is not completely true for complex and varying geometry. In fact, the experimental results highlighted how formability is influenced by the history of material deformation or by the thinning in the first part. For this reason, a geometrical condition α_1=75°-H_1=20mm and α_2=70°-H_2=70mm, which should corresponds to sound condition, actually failed after 26mm. It seems obvious that a more efficient control procedure needs to be based on the punctual measure of sheet thickness during the process development. In fact, it is very common to associate to the maximum thinning the maximum material formability in this process. Since this dimension can not be easily measured during the process and it is characterised by a polynomial trend, neither the Sine Law can robustly describe the material behaviour, an alternative solution can derive performing an optimised FE model.

4 NUMERICAL ANALYSIS

4.1 Model design

Despite it is a common opinion among the researchers that experimental approach usually supplies more robust data as compared to numerical simulation, nowadays remarkable improvements were introduced in the FE analysis thus dramatically enhancing its suitability. In the research here addressed, the code Dynaform® was used as simulation tool. It implements the dynamic equilibrium equations and results very efficient, also for the use of a smart remeshing criterion, based on the strain controlled shell element subdividing.
The simulation is conditionally stable because the imposed high speed of the punch may induce dumping phenomena. For this reason a check on the total kinetic energy was done, verifying that the imposed quota is less than the 10% of the total plastic energy, so that the dynamic effect in the simulation is negligible. The material behaviour has been supplied by a proper power law while the tool has been modelled as rigid surface.

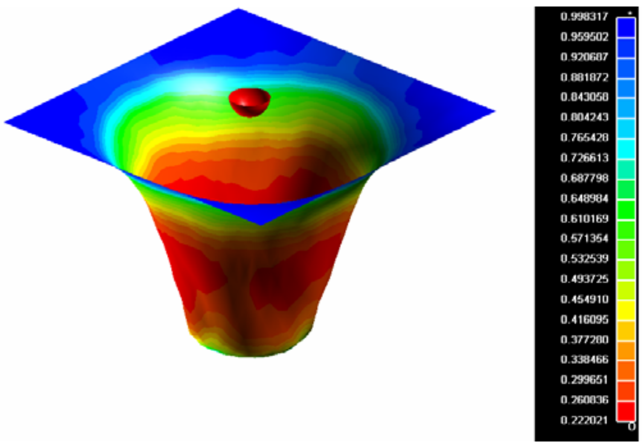

Fig. 4. Thickness distribution with α_1= 65° and α_2=70°.

4.2 Thinning analysis

At the end of the numerical simulations, each test was compared with the experimental one. The comparisons of both numerical and experimental measures are shown respectively for α_1= [65°-70°-75°] in the next figures 5, 6 and 7.
As it can be observed, a good overlapping was determined for the whole campaign; from a quantitative point of view, in fact, the maximum error is of the tenth of millimetres.

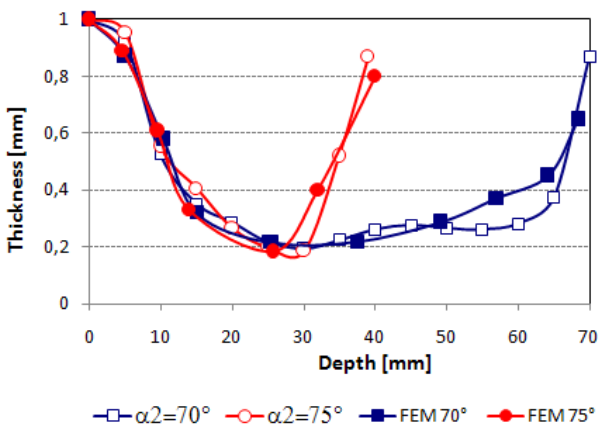

Fig. 5. Experimental-Numerical comparisons for α_1=65°.

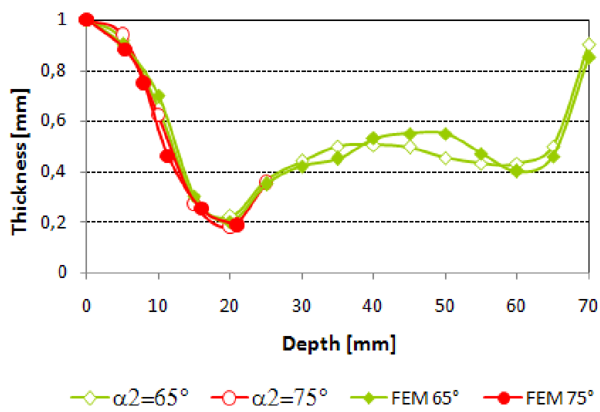

Fig. 6. Experimental-Numerical comparisons for α_1=70°.

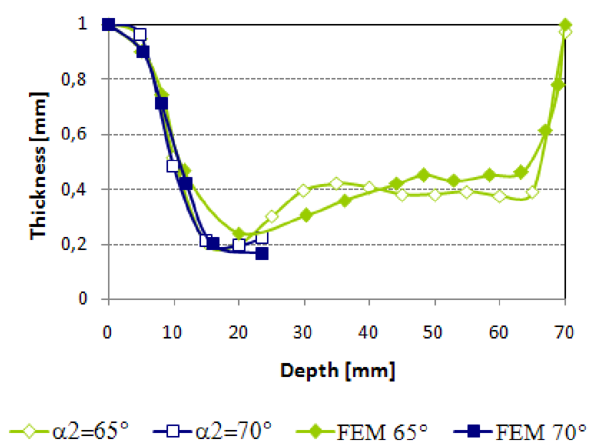

Fig. 7. Experimental-Numerical comparison for α_1=75°.

These results confirm the suitability of the FE simulation to predict material thinning even in IF processes. In this case, for instance, this constitute an interesting result since, how it can be observed in the previous figures, breaking occurs when thickness reaches more or less the value of 0.20 mm.

5 CONCLUSIONS

An effective design tool in ISF of multi-slopes shapes was set-up permitting to assess some interesting conclusions:

- despite the process mechanics in ISF is strongly localised, the product feasibility is not simply related to the process conditions and material properties but the sheet behaviour is directly influenced by the 3D profile;
- a suitable numerical model represents a good trade-off between CPU times and results reliability.

Starting from these assumptions, even if the model was validated on double-slope specimens, the approach can be easily extended to monitoring and control multi-slopes shapes.

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