A new accurate finite element method implementation for the numerical modelling of incremental sheet forming

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Abstract

The Incremental Sheet Forming (ISF) technology is becoming a modern and flexible rapid manufacturing process very useful in short-series production of metal parts for industrial applications.

This technology consists on forming a metal sheet by means of a spherical tool placed on the head of a conventional drilling machine controlled by 3 CNC axes or placed on a specifically designed ISF machine. The final shape is obtained according to a CAM-defined trajectory and usually employing a positive die support.

Many experimental efforts have been done to develop this technology but no specific software exists to simulate ISF processes in European context.

The new integration of CAD-CAM-CAE technologies provides high costs reduction, comprising a powerfull, predictive and accurate tool. Nowadays, real manufacturing process parameters can be used together with CAD and CAM definitions in order to perform CAE simulations of multi-stage ISF operations.

These integrated issues allow the manufacturer to scale up its own industrial ISF processes, by obtaining the final properties of the finished part starting from the initial material specifications.

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1. INTRODUCTION

The ISF process consists on applying a gradual deformation to the sheet metal blank through a spherical tool placed on the head of 3 axes CNC conventional drilling machine or in a specific designed machine for ISF processes. The final shape will be determined by the CAM trajectory with the aid of a positive die-support if necessary. The boundary of the blank is clamped.

Its main advantages over traditional forming techniques are:

- Shorter set-up process time.
- Lower price equipment investment due that not specific machine is needed. The 3D trajectory is defined by commercial CAM programs and a support can easily be made using wood, resins, aluminium, mild steels, etc.
- Cost, wearing and fracture of the tools are low.

- The dimensional accuracy, finished surface and reproducibility are function of the trajectory and friction conditions control.
- Scrap saving and flexible process.

However, there are also some disadvantages:

- The fabrication process is unitary.
- The production is economically limited to short series.

Another important aspect is that CAE software does not require specific hardware configuration. In fact usually powerfull home computers can work with it although workstations are strongly recommended.
For this paper, the main characteristics of the computer used for FEM simulations are:

Intel(R) Core(TM)2 Quad CPU Q9300, 2.50GHz, 3.48GB RAM

2. *FEM SOFTWARE DEVELOPMENTS*

This new FEM technology have been developed to provide the engineers a new powerful, predictive and accurate tool to obtain a final part successfully, using actual tools such CAD and CAM technologies joining them all in a new methodological process, as shown below ***(Figure 1)***[4][5]:

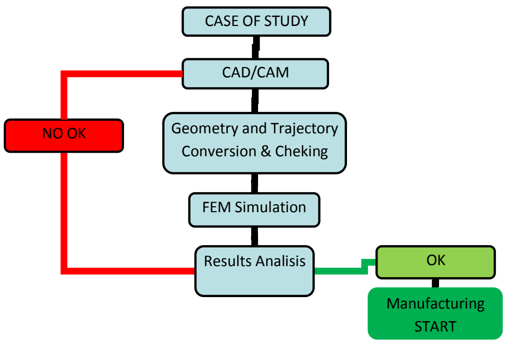

Fig. 1 - New methodological diagram flow

Seeing the diagram, once CAD and CAM definitions are finished, all the current data can be used to obtain a complete FEM simulation able to predict the model behaviour and to offer some results what allows taking the decision of starting with the part manufacturing or whether a new CAD/CAM redefinition is needed.
The FEM software capabilities offer the possibility of modelling a real case, allowing one stage or multistage forming operations. These features include the possibility of employing different tools.
The software employed to perform the FEM simulations is Stampack [1], an explicit code developed by Cimne and Quantech, which comprises state-of-the-art technology on metal forming, like the BST shell element[2-3] employed in the actual work.

2.1 *MATERIALS CHARACTERIZATION*

The materials characterization, true strain and stress, can be defined by the user, creating his own data sheet. The Nadai-Ludwick law may be calibrated by curve fitting employing least-square method:

$$\sigma_{real} = P1*(P2+ \varepsilon_{plast})^{P3}$$

where P1, P2 and P3 are the Nadai-Ludwick constants, fitted by least squares method from experimental tensile test points ***(Figure2):***

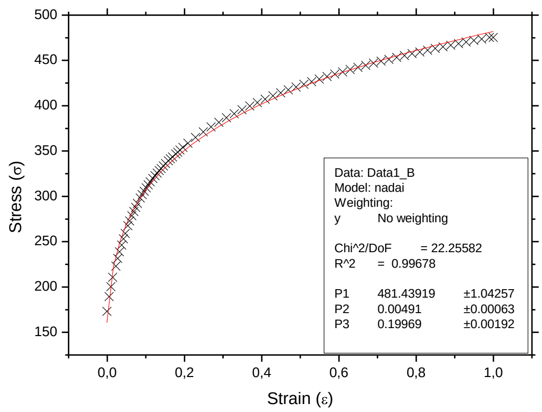

Fig. 2 - Strain-stress fitting curve

Also is used: E=2.1GPa; ν = 0.29 and transversal anisotropy R=1.77

2.2 *MESH REFINEMENT*

To optimize the accuracy, new refinement mesh algorithms have been specifically implemented for ISF FEM simulations allowing an optimal mesh control during the process.
Figure3 shows FEM case with no refinement application and in ***Figure4*** same case using ISF refinement algorithms:

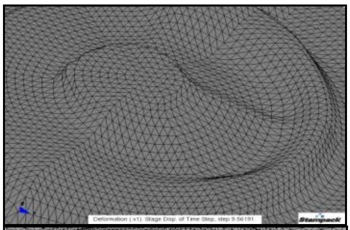

Fig. 3 - No mesh refinement

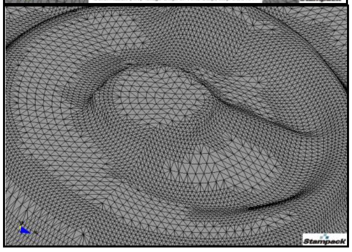

Fig. 4 - Mesh refinement

Using this new implementation the accuracy increases in final results, such is shown in ***Figure 5***:

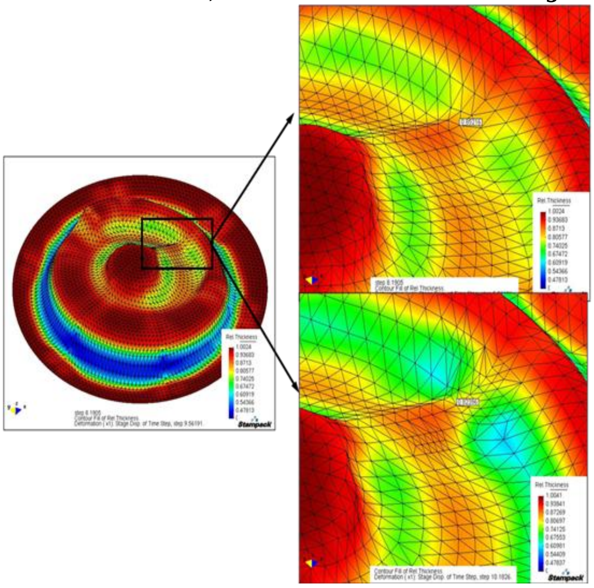

Fig. 5 - Final thickness comparison result

where in the same nodal point, more accurate relative thickness value has been obtained using refinement (0.823) than with no refinement (0.852). Experimental results show 0.831 on the same point.

3. MULTISTAGE STUDY CASE

The main limitation included in the ISF process is the one related with the maximum wall angle achievable in a part without material fracture, which is restricted to a maximum value of 60º.

As many industrial parts present higher wall angles it has been needed to develop advanced forming strategies consisting on manufacture the part in several forming stages. In this case the part is manufactured throughout the generation of some pre-forms until the desired shape of the final part is achieved. The deformation mechanism is quite complex, in this case, and the final result of the part in terms of thickness, stress and strains distribution is not known.

One of the major advantages of using FEM solutions is for the prediction of wall thickness distribution when multistage forming is needed and the use of this information to predict critical forming areas in the part.

The main features of the simulated part in multi-stage case are the following ***(Figure 6 & Table 1):***

Fig. 6 - Real final part

Part size	216.5x212.1 mm
Depth	45mm
Material	Mild Steel DC04
Tools	Tool 1 : Spherical punch Radius=15mm Tool 2 : Sperical punch Radius=5mm Tool 3 : Spherical punch Radius =2.5mm

Table 1 - Main part features

This part, supplied by: Edaetech & KYB Suspensions Europe has been simulated according real forming process conditions, using 3 different ISF forming stages and tools together with a positive die and blank holder as well ***(See Table 1):***

- **1st Stage – General forming strategy**

The simulation has been made using the movement of Tool 1. The input FEM trajectory definition is shown below ***(Figure 7)*** according to CAM output definition. This first stage consists on the obtaining of the general shape of the part without taking into account geometric details as small radius and features.

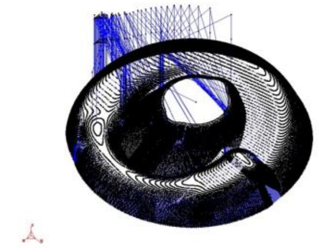

Fig. 7 First forming tool movement definition

- **2nd Stage – Detalied forming**

Second operation use small tool (tool2) to remake critical zones where big tool can not form properly because the tool radius is bigger than shape radius:

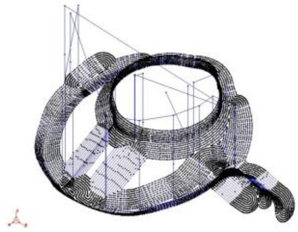

Fig. 8 - Second forming tool movement definition

- **3rd Stage – Re-strake and accuracy improvement**

In the last step, final geometry have been obtained using final tool 3, which provides the successful final desired geometry, using the smaller radius in the shape:

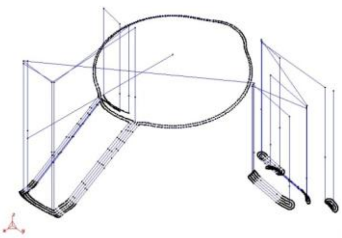

Fig. 9 - Third forming tool movement definition

This methodology allows the optimization of the multi-stage ISF process.

- **4th Stage – Cutting and springback operations**

To simulate the springback effects, a new operation is required. This operation consists on a cutting surface operation such in real part and a last springback calculus operation although no experimental results have been obtained:

The final obtained surface is shown in the next figure:

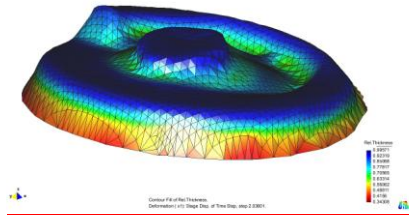

Fig. 10 - Cutting operation

4. MULTISTAGE STUDY CASE RESULTS

Once FEM simulation is finished, many results are available to be analysed such as: Principal strains, equivalent stress, and effective plastic strain, among others.

According to real measurements, the relative thickness is one of the main results to be analysed and compared with experimental results ***(Figure 11):***

$$Th_{final}=Rel.Th*Th_{initial}$$

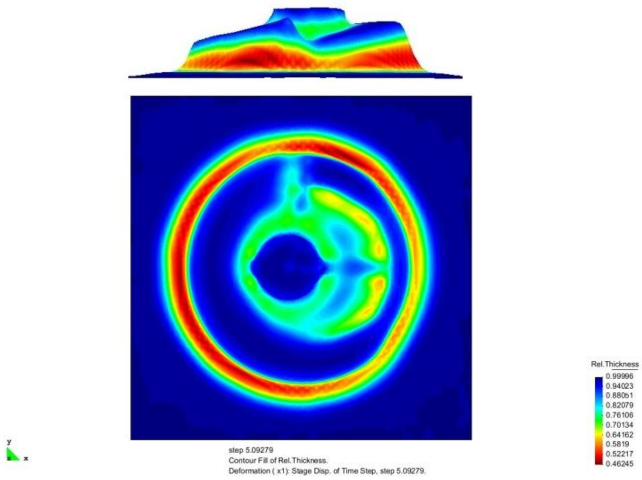

Fig. 11 - Relative thickness

5. EXPERIMENTAL VS SIMULATION RESULTS

Different comparisons using ISF forming processes versus conventional stamping process have been done and also FEM simulations versus ISF forming process as well.

To compare ISF forming versus conventionally stamped part, the resulting geometry ***(Table 2)*** has been measured in the points that are shown in ***Figure 12.*** These points correspond to different locations such as low inclination walls, high inclination walls and all of them with different depths.

The main ultrasonic measurement equipment characteristics are detailed below:

Microgage II of SONATEST. Thickness range 0.1-25 mm. And accuracy = ±0.001mm

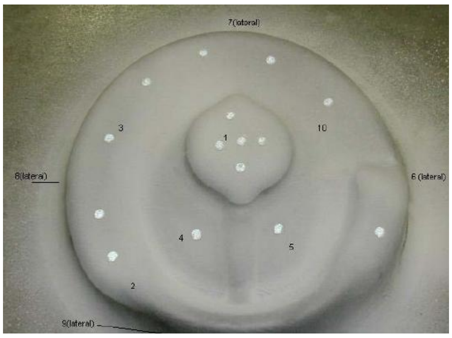

Fig. 12 - Measurement points identification on die

	ISF part		Stamped part	
Area nº	*Thickness (mm)*	*Thinning (%)*	*Thickness (mm)*	*Thinning (%)*
1	2,5	0%	/	/
2	2,402	4%	2,38	5%
3	2,394	4%	2,5	0%
4	2,14	14%	2,38	5%
5	2,038	18%	2,39	4%
6	1,53	39%	2,3	8%
7	1,56	38%	2,31	8%
8	1,66	34%	2,35	6%
9	1,54	38%	2,49	0%
10	2,34	6%	2,2	12%

Table 2 - Thickness measurement and comparison

Table 2 shows a great thinning, normally in high inclination walls with high depths. This issue reveals that high plastic strains are present in ISF forming processes.

Using same real part, manufactured by ISF a thickness comparison have been done showing great predictability accuracy between FEM and real process:

	Thickness measurement results		
Point	Experimental (mm)	FEM Model (mm)	% Max. Error
1	2.50	2.46	3.9
2	2.40	2.43	4.2
3	2.40	2.46	4.2
4	2.14	2.16	4.7
5	2.04	2.13	5.1
6	1.53	1.33	5.7
7	1.56	1.86	7.6
8	1.66	1.44	5.2
9	1.54	1.60	6.7
10	2.34	2.44	4.5

Table 3 - ISF vs FEM simulations thickness

In ***Table 3***, it may be seen that the maximum difference is located in point Nº 7 with a value of 8 % only. This great accuracy obtained demonstrates that great predictability can be obtained from the numerical simulation of ISF processes.

6. CONCLUSIONS

Multistage forming strategy has been shown as a good alternative for manufacturing complex parts with high wall inclination. The major need in this aspect is to define and to predict final thickness distribution in all around the deformed sheet.

The ISF method showed in this paper has been developed for the prediction of the thickness distribution in multistage forming operations and the results confirms a good reliability and predictability.

In this case, due the complexity of the final part, springback effects have not been relevant on this case of study.

Thickness reductions appear due to local ironing by contact forces between tool and sheet.

New tests using solid elements are still in study to know about stresses states that can be applied using this technology.

7. REFERENCES

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