FLEXFORM Project: Incremental Sheet Forming - an updated view. Integration of CAD, CAM and CAE technologies

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ABSTRACT: Incremental Sheet Forming-ISF) is a technique for forming framed sheet in rapid prototyping methods, which thanks to its efficiency, low cost and speed is developing rapidly and arousing growing interest. This article describes the main features of this technology with respect to its use with actual machine tools and a "virtual machine" (numerical simulation -CAE- based on CAD geometry definition and CAM definition for paths). It analyses the degree of integration, the respective results and development areas.

Introduction
The incremental sheet forming (ISF) process obtains formed sheets through the movement of a half spherical tool placed on the head of a conventional machine tool with 3-axis controlled CNC (machining centre, milling machine), or specifically designed for ISF: Paths may be defined in a standard CAM system. The final form of the part will be determined by the tool path and any support there may be.
It is thereby possible to obtain parts with complex geometries that would be too expensive to produce through traditional methods (drawing, fluid forming, elastomers, spinning, etc.) involving single parts or very short series.

ISF has arisen as an alternative to craftsman's methods that do not ensure productivity and dimensional reproducibility. It is destined to replace the above method, which depends totally on the ability of specialist personnel. Yet craftsman's methods are usually the only ones used when it involves single parts or very short series.

The main advantages of these types of processes with respect to conventional forming processes are:

- Depending on what final form is to be obtained, the process can be carried out without moulds (die less). In cases where supporting surfaces are necessary (to act as a die), these may be constructed from resin, wood, aluminium or conventional steels without great resistance and surface finish requirements.

- No special machine tools are needed in most cases. Parts can be formed using conventional CNC controlled 3 axis machining centres or milling machines with the addition of fittings designed to fasten the sheet.

- Tool costs are low since they are half spherical instruments. One tool per process is sufficient in most cases. If it is necessary to use more than one tool, to define radii for example, they would only differ in their diameters. They do not suffer great wear and the possibility of them breaking is low.

- Tool paths can be defined using commercial 3-axis CAM programmes without any special post-processing modules.

- Dimensional tolerance and constant surface finish are ensured on all parts since it is possible to use the same path and to check the interaction conditions with the sheet (relative speed and accelerations, lubrication, tool polishing level, etc.).

There are however some disadvantages:

- The production process is unitary, which means a single head machine will only be able to make one part at a time.
- In its present state, the methodology restricts production to short series.

- The times needed for CAE process simulation with a good level of accuracy (error of less than 2%) are greater than those for actual production of the part (simulation times are 2-4 times more than physical production).

Description of the process

ISF technology was initially conceived to work without any moulds (die less). In some cases, however, it is necessary to have a simply produced, fixed support to achieve the level of details and dimensional tolerances required. The sheet is fastened using quick clamps that are applied to a flat frame (a single part or a modular one in segments) which acts as a hold down plate. This ensures the perimeter of the sheet is perfectly fastened (not experiencing any relative movement in relation to it).

During this process, the tool does not cause swarf to be removed or any lamination. Tool-sheet contact is intermittent, and even if great contact forces and wear stresses are generated locally on the tool, the load transferred to the machine head is not excessive. Liquid lubricants are used to restrict friction. PVD coating, self-lubricants and ultrasonic techniques are being studied to improve tool-sheet interaction and to reduce or do away with the need for conventional liquid lubricants.

Description of an actual process

This article describes the actual production of a part that was defined and produced at the RWTH-IBF Institute [1] (see figures 1 and 2). This part was produced through the action of a Ø 10mm half spherical punch made of hard metal.
The sheet is held by a flat support frame with rounded edges that prevent the sheet moving in areas not affected by the punch (see figure 3). Sheet fastening is completed with a flat hold down plate that applies pressure to the sheet through quick adjusting clamps.
The parts were made, without breaking, using 1050 aluminium (non alloy aluminium with 99.5% purity) and DC04 steel (equivalent to FeP04 mild steel).

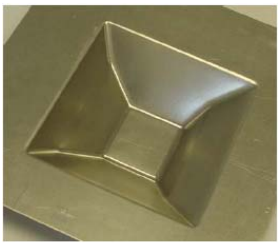


Fig. 1: Actual part produced (Courtesy of RWTH-IBF)

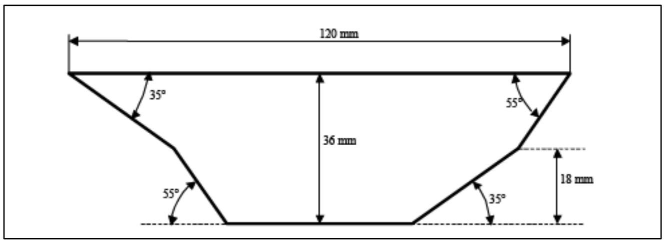
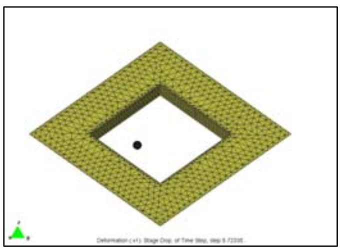


Fig.2: Side diagram with measurements (Courtesy of RWTH-IBF)

Computer simulation of the process

For virtual simulation of the process described, specially designed software is used, developed in the context of the FLEXFORM project (FP6 Collective Research: Proposal no. 0302273), coordinated by ASERM (Spanish Association of Rapid Manufacturing). This software is based on the finite elements method (FEM), the starting point for this being the STAMPACK® general purpose code for metal forming, which is widely established in industry.

Virtual punch movements and sheet fastening are defined in the same way as in the actual process. The programme has a dialogue menu with the user to transfer the path from the CAM environment in ISO format, and sheet and tool geometries from the CAD environment in IGES format or similar [3]. Figure 4 shows the path where the tool centre is taken as the reference.



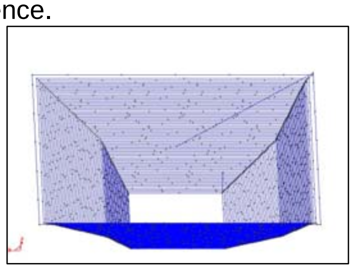


Figure 3: Support frame and spherical punch.

Figure 4: Path generated in CAM and already processed in the simulation programme by FEM.

The main difficulties in simulating these types of processes lie in processing the contact force between the tool and the sheet and the high speeds and accelerations produced in the contact area and its surrounding area. Accuracy in processing the tool path is also a factor of great importance. Tests carried out with the current software version, under development, have made it possible to restrict error in path description to less than 0.01 mm. (see figure 5).

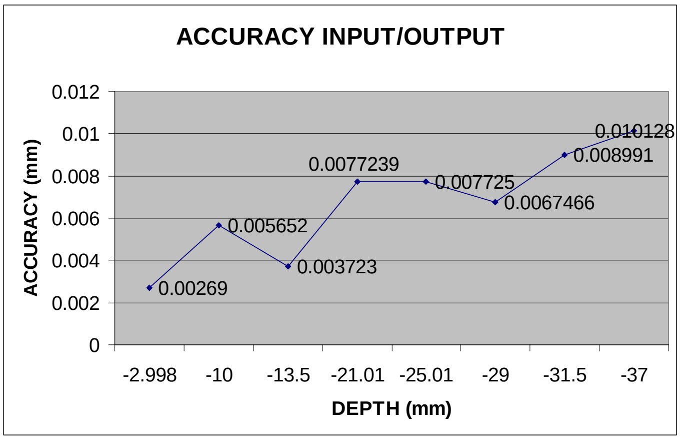


Figure 5: Evolution of absolute error between real and simulated path.

Comparing test and simulated results

To assess the performance features and capacity of the software being developed, and to virtually reproduce ISF processes, we should stress the following aspects:

- Path reproduction: The level of correspondence obtained between the actual path and simulated path is high. Absolute error is around 0.01 mm (see figure 5).
- Forming reproduction on the sheet surface. Figure 6 shows the maximum possible forming for the end of the process corresponding to Aluminium 1050.

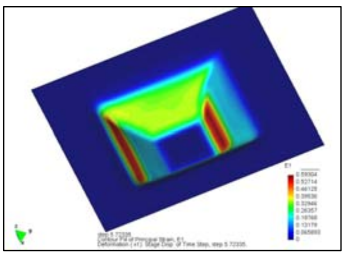


Figure 6: Maximum possible forming (end of process for Al 1050).

Figure 7 shows the minimum possible forming for the end of the process corresponding to Aluminium 1050.

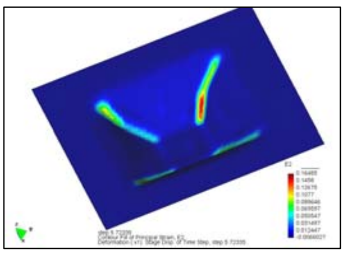


Figure 7: Minimum possible forming (end of process for Al 1050).

- Thickness reproduction: Figure 8 shows thickness forming. The change in thickness with respect to initial thickness is considered ($\frac{\Delta e}{e_0} \cdot 100$)

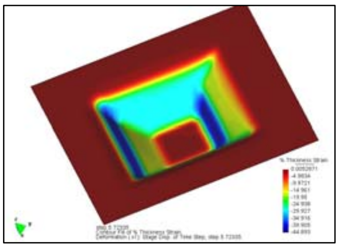
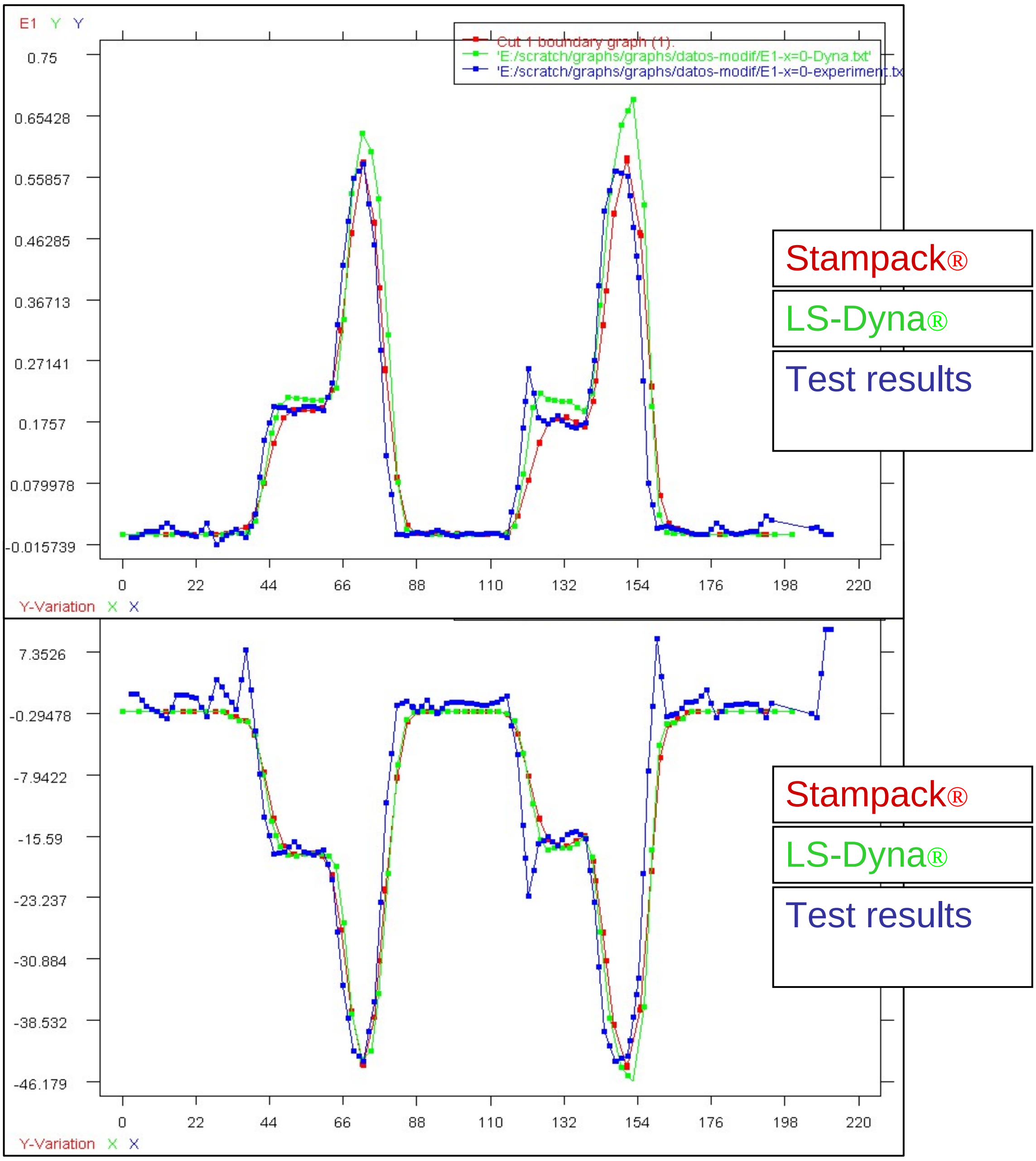


Figure 8: Thickness forming (end of process for Al 1050).

To assess the quality of the results obtained by simulation, we have chosen to compare test results [1] with those from simulation using the LS-Dyna® commercial programme. It can be seen in figures 9 and 10 that the degree of correspondence with test results is excellent and in some areas improves on those obtained with LS-Dyna®. Time spent on full process simulation with a conventional PC type computer is approximately 20 hours.



Numerical simulation has made it possible to cut the excess metal sheet, as well as allowing elastic recovery of the resulting part (see figures 11 and 12).

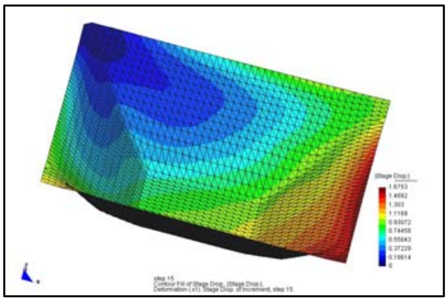


Figure 11: Cutting excess sheet .

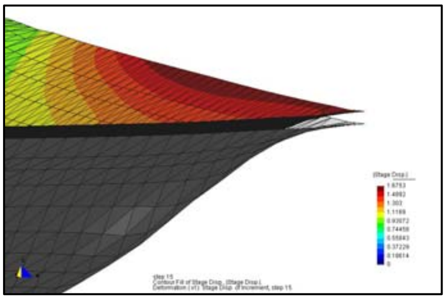


Figure 12: Elastic recovery of the part after the full process.

To allow elastic recovery of the part, it is necessary to fasten some points of the part. In the case shown in figure 12, one of the corners of the part has been fastened and the rest of the sheet has been left completely free.

To conclude

The following aspects can be stressed after analysing the test and simulation results:

- Tool path processing is correct. The difference between the data defined in the CAM environment and the path obtained in simulations is compatible with industrial requirements.
- Differences between test results and CAE simulations, in terms of sheet surface forming and thickness forming, are less than 2%.
- The times needed for CAE processing simulation, with the level of accuracy shown, are more than those in actually producing the part to an acceptable level (2-4 times more). Current development work is aimed at continuing to reduce these times without affecting the level of accuracy.

REFERENCES:

[1] RWTH-IBF, Deliverable 1-5_FLEXFORM project, Parameters for the FEM-simulation, May 2007.

[2] CIMNE, Activities progress report M1-M12_ FLEXFORM project, Barcelona, October 2007.

[3] Márquez, J., et. al, Study of Incremental sheet forming processes, Technical report, CIMNE IT s/n, Barcelona, June 2007.