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BEHAVIOUR MODELLING of ALUMINIUM ALLOY SHEET FOR SINGLE POINT INCREMENTAL FORMING

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Introduction

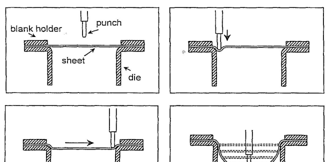
The SPIF process :

The Singe Point Incremental Forming (SPIF) : a new forming process used in sheet metal forming. Different steps of this process are shown in figure [1]. Incremental displacements of the punch in various directions allow to form the sheet in order to provide the required shape.

Advantages : - best formability of sheets
- reducing costs when prototypes or batches have to be manufactured

Drawbacks : - manufacture's times longer
- sometimes poor geometry's respect and surface aspect
- time-consuming Finite Element simulations because of the incremental characteristics of the process.

[1]



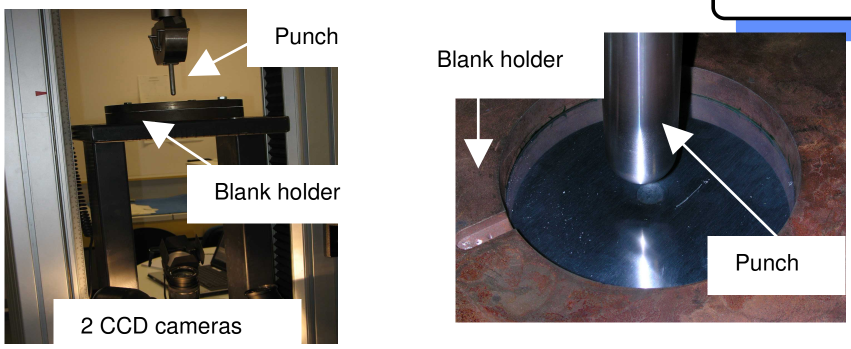
[1] Kim T.J. et Yang D.Y., "Improvement of formability for the incremental sheet metal forming process", *International Journal of Mechanical Sciences*, 42, (2000), pp. 1271-1286.

Methodology of the work:

Before to study the sheet behaviour on SPIF and the way to form influence, a more simple test with just a perpendicular punch displacement on the sheet is used : incremental stamping test.

A proposed behaviour model is identified using classical tensile tests. Simulations of incremental stamping test are thus compared with experiments using 3D-Digital Image Correlation (3D-DIC).

Incremental Stamping Test

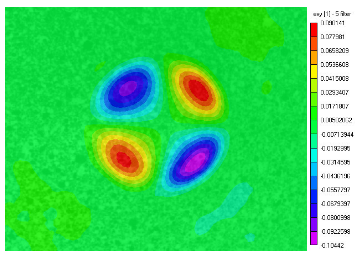


Experimental set-up

- Electromecanic INSTRON test machine in compression mode.
- Alloy aluminium sheet 2024-T3.
- Cylinder punch with steel hemispheric head in 30 mm diameter.
- Datas : compression force, punch displacements and strain fields obtained by 3D-Digital Image Correlation (3D-DIC).

Speckle pattern on the sheet

Shear strain field for a15 mm punch displacement obtained by 3D-DIC



The cameras field of view corresponds to the area studied (Area Of Interest, AOI)

Modelisation

Elasto-plastic model in planes stresses: Hill's yield criterion and isotropic-kinematic hardening.

$$f=\sqrt{H((\underline{\underline{\sigma}}'_{11}-\underline{\underline{X}}_{11})-(\underline{\underline{\sigma}}'_{22}-\underline{\underline{X}}_{22}))^2+F(\underline{\underline{\sigma}}'_{22}-\underline{\underline{X}}_{22})^2+G(\underline{\underline{\sigma}}'_{11}-\underline{\underline{X}}_{11})^2+2N(\underline{\underline{\sigma}}'_{12}-\underline{\underline{X}}_{12})^2}-R-R_0$$

R : Isotropic hardening $R=Q(1-e^{-b\dot{\lambda}})$

$\underline{\underline{X}}$: Kinematic hardening $\underline{\underline{X}}=\frac{2C\underline{\underline{\alpha}}}{3}$ with $\dot{\underline{\underline{\alpha}}}=\dot{\underline{\underline{\varepsilon}}}_p-D\underline{\underline{\alpha}}\dot{\lambda}$

R_0: Yield stress

F,G,H,N: Hill's coefficients
Q, b, C, D: Materials parameters

$\dot{\lambda}$: Plastic multiplier, calculated from the consistency condition: $f=\dot{f}=0$ => $\frac{\partial f}{\partial \underline{\underline{\sigma}}}:\dot{\underline{\underline{\sigma}}}+\frac{\partial f}{\partial R}\dot{R}=0$ thus $\dot{\lambda}=H(f)\frac{1}{h}\left\langle\frac{\partial f}{\partial \underline{\underline{\sigma}}}:\dot{\underline{\underline{\sigma}}}\right\rangle$ with $h=C-\frac{3D}{2}\underline{\underline{X}}:\frac{\underline{\underline{\sigma}}'-\underline{\underline{X}}}{J2(\underline{\underline{\sigma}}'-\underline{\underline{X}})}+b(Q-R)$

Identification

Parameters identification:

- Tensile tests in 3 directions (α) between the traction axis and the rolling direction of the sheet (0°, 45°, 90°). Use of DIC to calculate r(0°), r(45°) and r(90°).
- Hill parameters are first identified by the anisotropy coefficient r(α).

$$r(\alpha)=\frac{\dot{\varepsilon}^p_{22}}{\dot{\varepsilon}^p_{33}}=\frac{4-4G-(F+4-3G-2N)\sin^2(2\alpha)}{2((G-F)\cos(2\alpha)+F+G)}$$

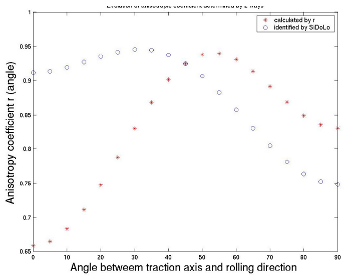
- Observation : weak anisotropy of sheets.

Parameters identified by optimisation between experimental and simulated tensile tests (SiDoLo software):

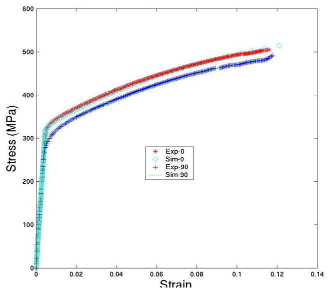
- Elasticity => R_0=320 MPa ; E=70 GPa
- Isotropic hardening => Q=269 MPa ; b=10,4
- Kinematic hardening => C=4985 MPa ; D=510

Hill's parameters	G	F	H	N
Calculated by r(α)	0,603	0,478	0,397	1,541
Identified by SiDoLo	0,523	0,637	0,477	1,653

Evolution of the anisotropy coefficient determined by 2 ways



Comparison between experimental and simulated strain-stress curves



Choice of the values of Hill's parameters identified by SiDoLo (best fit on tensile curves)

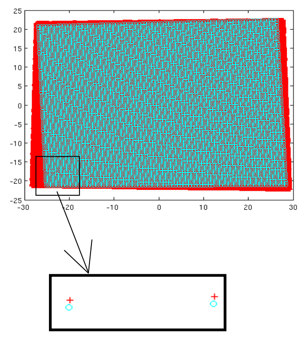
Stamping incremental test's results and simulations

Geometry:
- Sheet dimensions = AOI,1 mm thickness.

FEM software:
- Abaqus^{TM}/explicit, continuum shell elements, 9 integration points in the thickness.

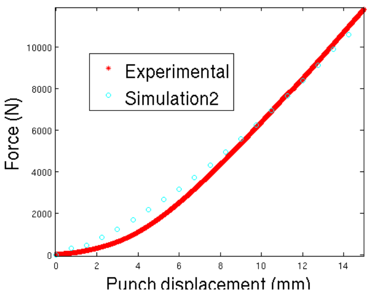
Boundaries conditions:
- Punch (considered as rigid body) displacement.
- Friction coefficient 0,2.
- Sheet's periphery displacement is imposed:

=> Experimental 3D-mesh projection on the FEM model.
=> Extractions of node's displacements vectors of the AOI periphery.

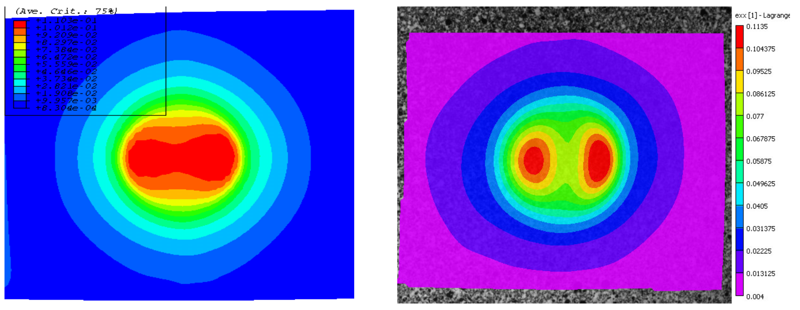


Cracked sheet: U_{Punch} > 15

Evolution of the global force versus punch displacement



Comparison of the (ε_{xx}) strains fields results



Abaqus^{TM} Vic-3D®

Conclusion and future works

- Hill's yield criterion of plasticity and isotropic-kinematic hardening have been well identified based on tensile test.
- For the stamping simulation, measured displacements as boundary conditions at the periphery of the AOI, allows to obtain similar results in comparing global force versus punch displacement and strain fields.
- Work is going on by the use of SPIF process with 3D-DIC measurement and comparing with FEM simulations.
- In this case, the parameters of the model, or the model itself, will need to be improved.