SPRINGBACK AND TWIST PREDICTION OF ROLL FORMED PARTS

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Abstract

In the construction market, Roll Forming is the reference forming process. Numerous parts are achieved in such a way: purlins, steeldecks or suspended ceiling parts are examples of it. Roll Forming is also more and more used in the automotive industry, as it constitutes a good alternative to forming for High Strength Steels.

Among the major requirements to obtain a defect-free product are outlined: the accurate geometry of the part, the taking into account of the springback as well as the prediction of twist. Furthermore, the roll forming operation could be only the first forming operation: the part could be curved or locally deep drawn afterwards. FE codes could allow fulfilling these requirements. However, they need significant advances in terms of material model description and numerical development.

This paper presents the work done in order to predict the geometry and the behaviour of a roll formed part:

First the material is characterized in complex strain paths in order to identify elaborated microstructural model like Teodosiu's one. This model is able to take into account Bauschinger effect, orthogonal strain paths, isotropic/kinematic hardening. The METAFOR code is then used to have a better understanding of the mechanics of the deformation of the strip during the forming process.

Several experimental campaigns were performed on the I-R&D ARCELOR roll forming machine to define a strong database in order to validate the numerical results. The geometry of machine as well as the shape of the channels inside and outside the RF machine were measured. Some experiments were even carried out in order to generate defects like twist in the roll formed profile.

Keywords: Roll Forming, Springback, Simulation, Experiment, Twist, IDDRG2006

1. Introduction

Roll Forming (RF) is the reference forming process in the construction market. Numerous parts are achieved in such a way: purlins, steeldecks or suspended ceiling parts are examples of it (**Figure 1**). Roll Forming is also more and more used in the automotive industry (**Figure 2**), as it constitutes a good alternative to forming for High Strength Steels.

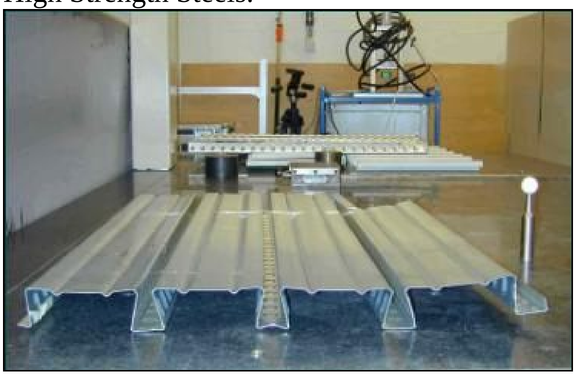

Figure 1. Roll formed steeldeck

Figure 2. Front bumper beam

Cold roll forming is a progressive and continuous process, in which small amounts of forming are applied in each stand until obtaining a 3-D cross-sectional profile.

Analytical and experimental approaches have been employed for the study of cold roll forming of simple profiles or pipe sections [4]. In order to analyze more complex profiles and to obtain in details the distribution of stress and strains in the formed sheet, numerical methods are used. The finite strip method appears attractive [5], but a judicious choice of longitudinal shape functions is required. Being able to deliver exact and effective solutions in metal forming processes, the use of the finite element method is increasingly adopted in the simulation of the cold roll-forming process [6,7,8]. In this regard, several finite element packages as Abaqus, Marc, Profil 7, Copra FEA …, which are capable to handle large strains problems together with complex boundary conditions like friction and frictionless contact, and with sophisticated movements of forming tools, begin being used for the simulation of the cold roll-forming process. However some limitations still exist in terms of reliability, CPU time, contact problems or possibility of an additional forming operation.

In this work, a 3D finite element analysis is involved to study the deformation of strip during and after the forming process. In order to validate the reliability of the simulation, numerical results are compared with experimental data.

Springback and twist are major concerns in forming after bending/unbending. It is well known that a good model of materials, especially a correct description of plastic behavior is important to the quality of simulations. An elaborated material model like Teodosiu's one [9], where the isotropic and kinetic hardening is associated with the microscopic dislocation structure, enables a true description of material behavior in particular the Bauschinger's effect as well as the possible softening after orthogonal strain paths. It is however achieved at the cost of a complex identification procedure. The interest of such a description strongly depends upon the material as well as the forming process and is investigated for a U-shape profile. We adopt kinematic Armstrong-Frederick model, or isotropic Swift model or a mixed-hardening model coupling both approach, which does not require important effort in the identification, and still allows a fairly accurate description of plastic behavior of the material.

Several experiments are carried out based on a DP980 cold rolled steel which is more and more used in roll forming for automotive applications (see Table I).

Table I : Nominal characteristics of DP980

Material	**Direction**	**Thickness (mm)**	**YS (MPa)**	**TS (MPa)**	**A80 (%)**	**n_{90}**
Dual Phase 980	Rolling	< 3	550 - 700	980 - 1100	≥ 10	-

2. Material description

2.1 DP980 characterization [1]

The characterization of the Dual Phase DP980 steel sheet of 1.6 mm thick relies on monotonic tensile tests, on monotonic and reverse simple shear tests, performed in different directions from the Rolling Direction.

The simple shear tests are performed in the bi-axial machine (**Figure 3**) developed by Flores [1] able to simultaneously or successively apply plane strain tensile and simple shear states. In every case the piston speed remains constant at 0,005 mm/s. As observed in Figure 4, the material presents a clear kinematic behaviour.

Strain measures are taken with strain gauges (rosettes, strain measure capacity up to 5%) for the identification of the elastic parameters and the determination of the yield limit. Aramis® optical extensometer is used to measure the strain field in order to compute the Lankford coefficients. Strain gauges perform better for small strains rather than the optical measurements. Stress is computed from load cell data.

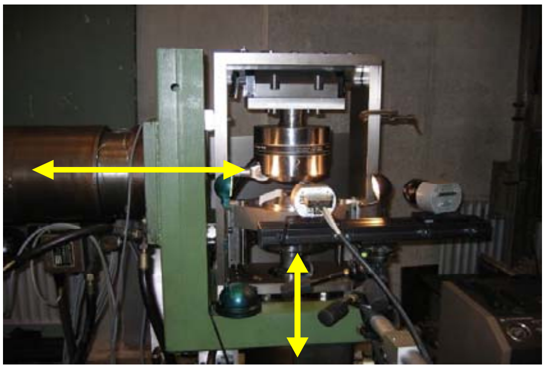

Figure 3 : Bi-axial machine used to perform simple shear tests

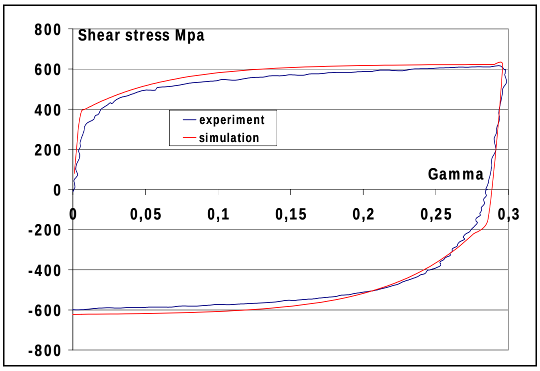

Figure 4 : Baushinger simple shear test (Sim/exp)

2.2 Material model

As the mean measured Lankford coefficient was 0.93 (r_0=0.86, r_{45}=1.00 ,r_{90}=0.88), it was decided to neglect plastic anisotropy and to use an isotropic elasto-plastic model of von Mises type. This isotropic behaviour was also observed in the elastic strain range, so mean isotropic parameters are used: the Young modulus is 188439 MPa when the Poisson ratio is 0.295. These apparent values are measured from tensile tests with loading and unloading sequences at low plastic strains. The initial flow stress measured for 0.2% of plastic strain is 697.3 MPa.

The shear Baushinger tests performed after 20% or 40 % of pre-strain reveal that this material presents no stagnation of the hardening when the strain path is reversed (**Figure 4**). Classical isotropic hardening model could not even model both monotonic tensile and shear tests when the Armstrong-Frederick kinematic hardening model allows simulating both monotonic tests and the Baushinger shear test. The saturation of the back-stress is defined by X_{SAT} and its respective saturation speed is C_X. The objective derivative of the back-stress $\overset{\nabla}{X}$ is:

$$\overset{\nabla}{\mathrm{X}} = C_X \left(X_{SAT} \mathrm{d}^p - \mathrm{X}\dot{p} \right) \tag{1}$$

where d^p is the plastic strain rate tensor and $\dot{p}$ the equivalent plastic strain rate, C_X=43.7 and X_{SAT}= 199 MPa.

3. Experimental set-up and numerical simulations

3.1 Experimental set-up description

Experiments are performed on the ARCELOR I R&D cold-roll forming line. The latter is composed of 6 stations, which allow bending a U-shape (**Figure 5**). The stands are equally spaced of 500mm. The machine is supplied with blanks of the dimension 2000x200x1.6mm.

Figure 5. Experimental forming line

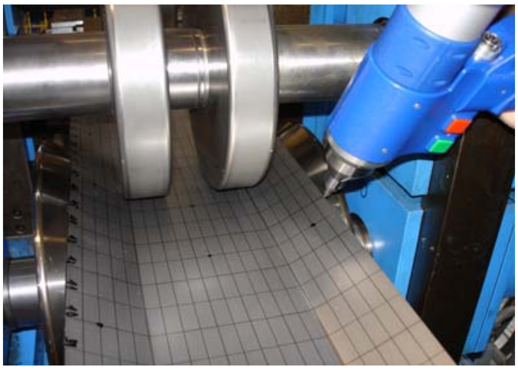

Figure 6. 3D measurements in the RF line.

Once the sheet was in the RF line, transversal and longitudinal sections were measured on the upper skin of the deformed sheet (**Figure 6**) in order to get a full description of the sheet geometry being deformed. The actual geometry and position of the tools were also checked in this way. The presence of springback, twist and camber in the product are then assessed in a 3D CM machine (**Figure 7**).

Trials were done under several configurations of the forming line (**Table 1**). First and second campaigns were performed in the nominal conditions of the roll-forming practice, whereas the forming line was deliberately modified in the third and the fourth campaigns in order to trigger some defects into the final product:

- Indeed, one of two upper rolls at the 4th stand was removed in the third experiment.
- Finally, two upper rolls at the 2nd and 5th stands were taken away in the fourth experiment (**Figure 8**).

Table 2. Different configurations of experiments

Experiment number	Radius of profile		Removal of upper rolls	Presence of twist	Symmetry of mesh
	left	right			
1	R6	R6	-	no	yes
2	R6	R2	-	no	no
3	R6	R6	at station 4	yes	no
4	R6	R2	at stations 2 & 5	yes	no

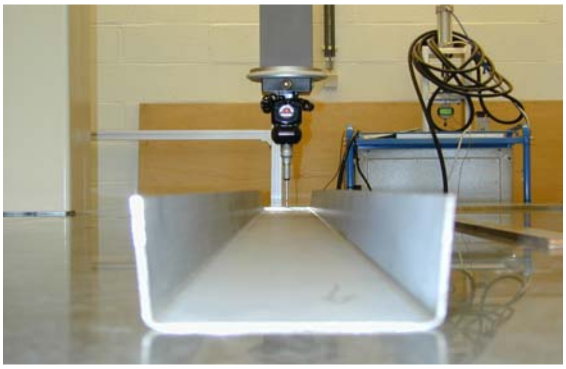

Figure 7. 3D profile measurement.

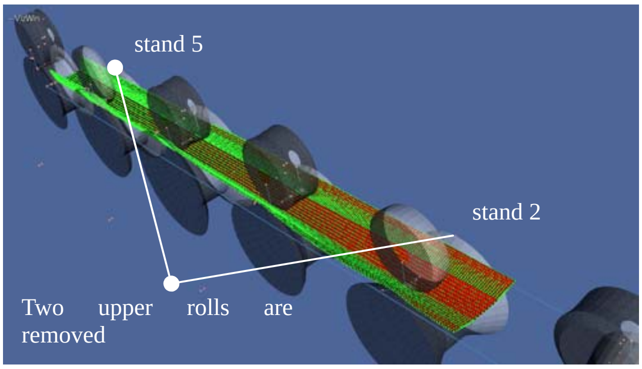

Figure 8. RF machine configuration to generate twist.

3.2 Finite element modelling

The simulation was performed using the finite element code Metafor [2] dedicated large strains simulations. Solid 8-node elements with an enhanced assumed strain (EAS) formulation [3] were used for the modelling of the blank, and a mesh refinement was made in the folding zone, where an important amount of plastic flow was expected. Due to the use of EAS elements and their efficiency in bending, only one layer of elements has been used. The rolls are supposed to be perfectly rigid and their circular geometry has been exactly taken into account (no discretization of the rigid tools) (**Figure 8**).

The contact condition between the sheet and rolls is enforced by the penalty method, and a sufficiently high value of penalty parameter κ = 1.E4 N/mm is adopted. In case the forming line is complete (no tool removal), only one half of the structure needs to be modelled due to symmetry. It allows a more economic computation, and a mesh of (400x22x1) elements has been used. In non-symmetrical cases, the whole structure has been discretized with a mesh of (300x36x1) elements.

The mixed Armstrong-Frederick hardening model is used for all the numerical simulations.

3.3 Comparisons between numerical and experimental results

Experiment 1. A good agreement between the experimental measurements and the numerical simulation is found for the deformed shape of the sheet at different stages of the forming process (**Figure 9**).

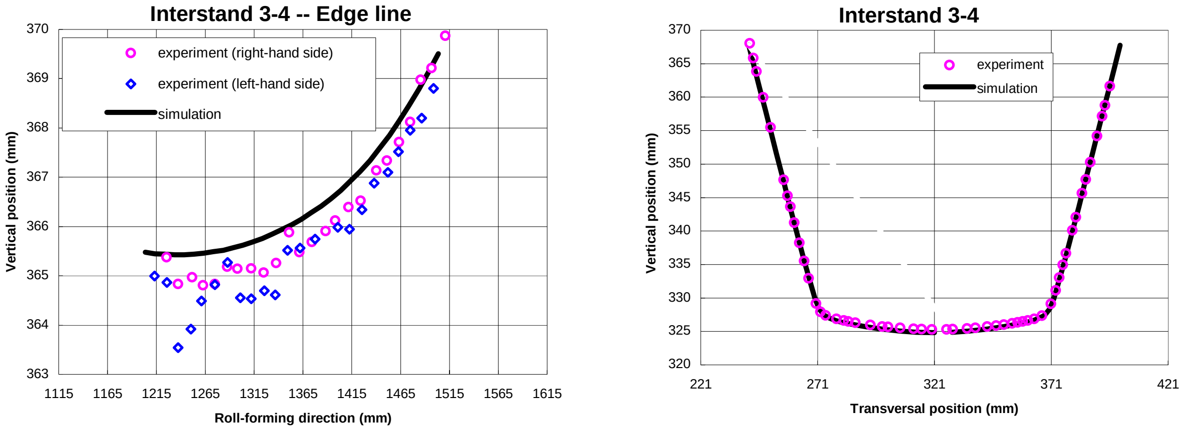

Figure 9. Deformed shapes of sheet along longitudinal lines and intermediate sections (Experiment 1:R6/R6)

Springback of the product is clearly observed and is well predicted by the simulation (**Figure 10**).

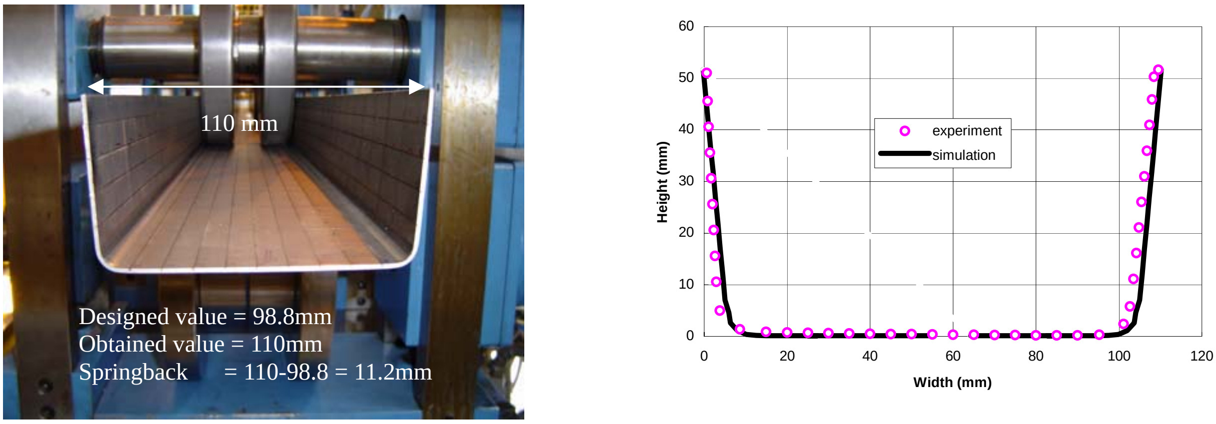

Figure 10. Springback of U-profile (Experiment 1:R6/R6)

<u>Experiment 2.</u> Two different forming radii of the profile are present in configuration 2. A good agreement is also found between simulation results and experimental data (**Figure 11a**). Small differences at the edges are due to imperfect experimental blank centering. Based on this configuration, the influence of the hardening model is also considered. **Figure 11b** compares the predicted springback when using either the mixed Armstrong-Frederick and Swift isotropic hardening models. The latter is also adopted elsewhere [7]. The result is also very comparable although the Swift model cannot give a correct description on the Bauschinger's effect. Hence, the latter is certainly not important in the present problem: The unloading subsequent to the forming in each RF stand remains elastic. There are no plastic bending/unbending.

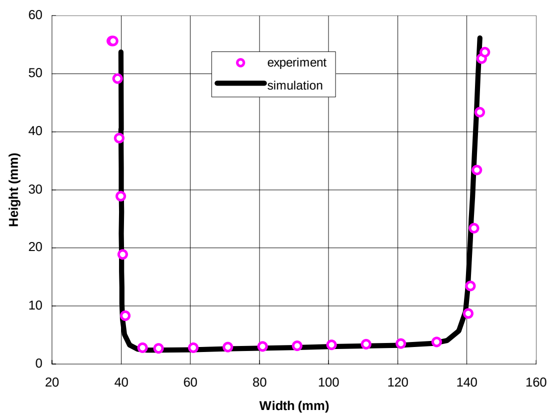

Figure 11a. Springback of U-profile (Experiment 2:R2/R6)

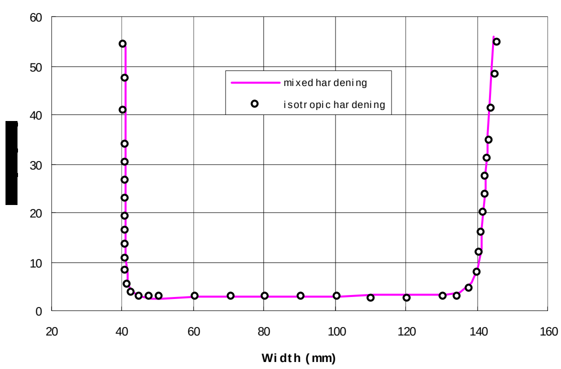

Figure 11b. Influence of hardening model (exp R2/R6).

Experiment 3. It is quite similar to the configuration 1, except the removal of an upper roll at the station #4.

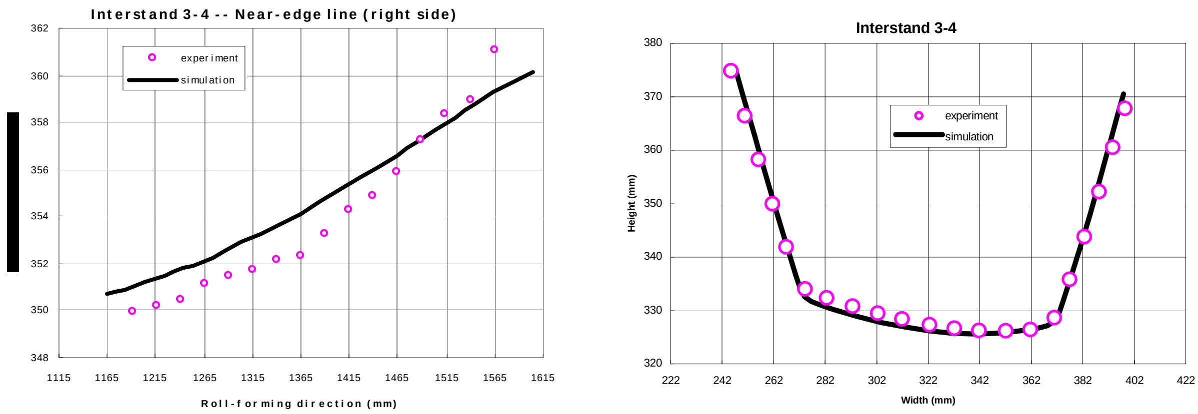

Figure 12. Deformed shapes of sheet along longitudinal lines and intermediate sections (Experiment 3:R6/R6)

This configuration inevitably alters the symmetry feature of the forming action, and hence generates slight twist on the final profile (**Figure 12**). Once more, the simulation allows a rather realistic description on the forming process. The prediction of springback is also in a good agreement with the experiment (**Figure 13**).

Note that section 0mm is maintained horizontally.

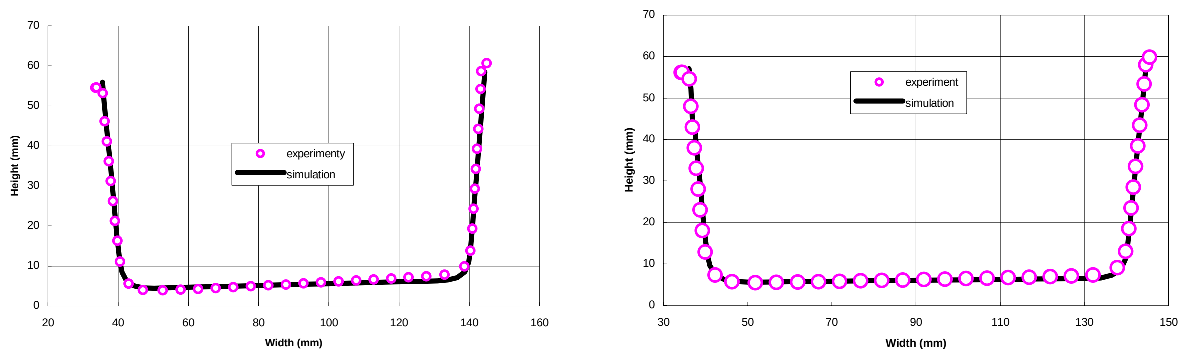

Figure 13. Springback at U-profile (Experiment 3:R6/R6)
(measured at 500mm (left) and 1000 mm (right) from the entering front of the sheet)

Experiment 4. The complexity strongly increases in the 4th configuration: The profile is unsymmetrical as for experiment #2 but two upper rolls are removes in stations #2 & #5. Despite these difficulties, the numerical simulation faithfully correlates the experimental geometry of the part. (**Figure 14**).

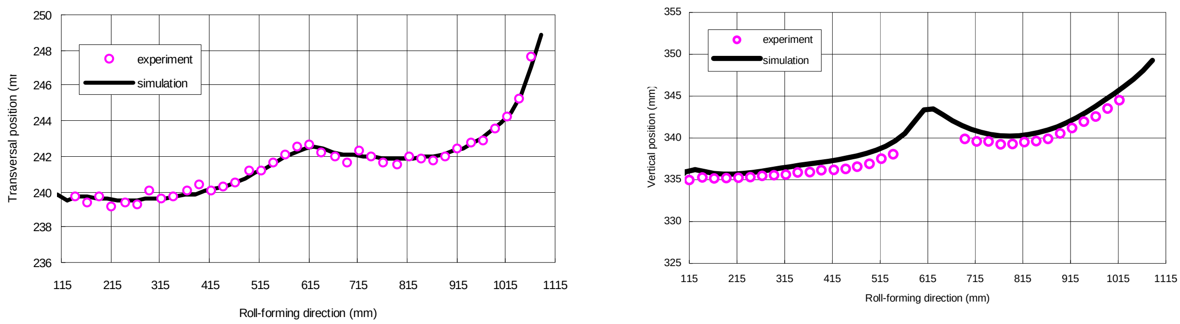

Figure 14. Evolution of the near-edge line at different interstands 1-2-3 (Experiment 4:R2/R6)

Once the forming operation is terminated, an examination of the product at different sections reveals the presence of springback together with the occurrence of an important twist. Again, the numerical simulation enables a rather correct prediction of the amount of springback and a truthful trend of twist (**Figure 15**).

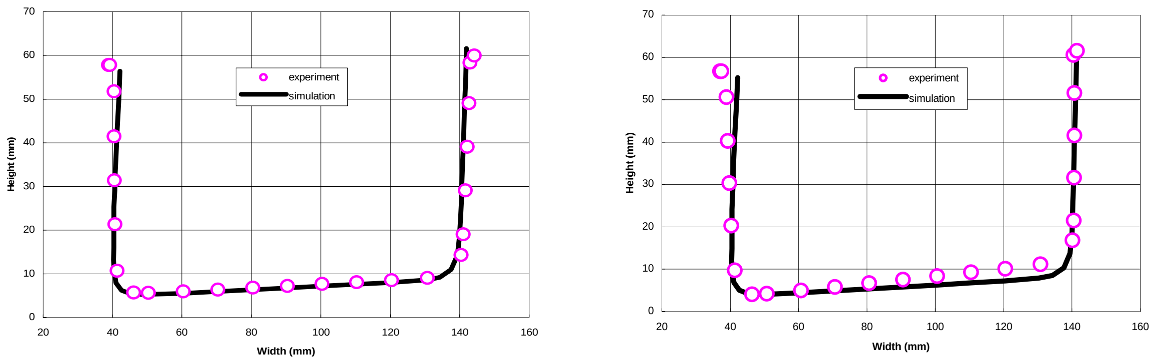

Figure 15. Springback and twist at U-profile (Experiment 4)

(measured at 1000mm (left) and 1500 mm (right) from the entering front of the sheet)

4. Conclusions

This multi-disciplinary teamwork demonstrates the interest of FE modelling to predict the behaviour of a profile during roll forming as well as in-service.

According to the RF machine and the material, twist and springback could be assessed. Important experimental campaigns allowed validating the reliability of the simulation. However, several requirements are compulsory :The FE code must be capable to handle large strains problems together with complex boundary conditions like friction contact, and with sophisticated movements of forming tools. About the material model, it was shown that for a simple U-shape profile for which the strain paths are not reversed i.e. without bending/unbending a simple model could be used. Once combined, all these features allow having reliable solutions in acceptable CPU time.

Roll-forming simulation with adequate FE code is attractive. Future works are devoted to model successive forming processes :

- Roll forming could be the first forming operation and could be followed by an additional operation like draw bending.
- The origin of defects could be also analyzed as either generated in the RF line due to inadequate RF flower or consequence of an original defect in the coil like long edge.

5. References

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