Process Rules for Sheet Metal Hydroforming

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ABSTRACT

It is said many times that sheet hydroforming [1] is considered a good opportunity for industrial applications related to niche and medium-low volumes productions. Nowadays this technology has not found a specific application contest like it is for tubes hydroforming. In this last case, its large application to industrial cases has allowed to define through appropriate experimental validations “best practice” rules for the process design [2] and for its tryout [3][4][5].
In this specific case, a “shape factors” set has been defined with the proper goal to use it in order to classify metal components production through the application of sheet hydroforming. Finite Element Analysis (FEA) has been extensively used in order to investigate and define each shape factor with a proper comparison to the macro feasibility of the chosen component geometry. These shape factors have been used to track the process performances through their variation thanks to the usage of the numerical simulation which will be later validated with an appropriate experimental campaign which will be executed thanks to the usage of a specific equipment properly designed.

INTRODUCTION

Among all the possible components classes “producibili/ottenibili” thanks to sheet hydroforming specific applications related to the automotive industrial segment have been chosen. Typical examples are represented by external panels (Figure 1) and fuel metal tanks with complex geometries.

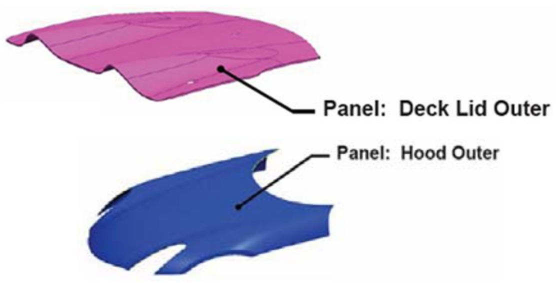

Figure 1: some industrial examples of components obtained with sheet hydroforming.

The feasibility configuration definition for a given shape can be done through an appropriate study of the influence of each process variable for sheet hydroforming on the process performances. The n-process variables define a process feasibility space made by n dimensions. With a proper evaluation of the influence of each process parameter on the process performances through the extensive usage of Finite Element Analysis a feasibility window can be defined. A subdomain of the feasibility window is the Process Window which takes into account all the possible constraints due to the available equipment characteristics like: maximum fluid chamber pressure, maximum blankholder force and its distribution, maximum pre-forming height, etc. Even if it is not possible to represent the n-dimensions space representative of the process feasibility a schematic representation can be adopted in order to understand which the process sensitivity to the variation of its variables is (Figure 2).

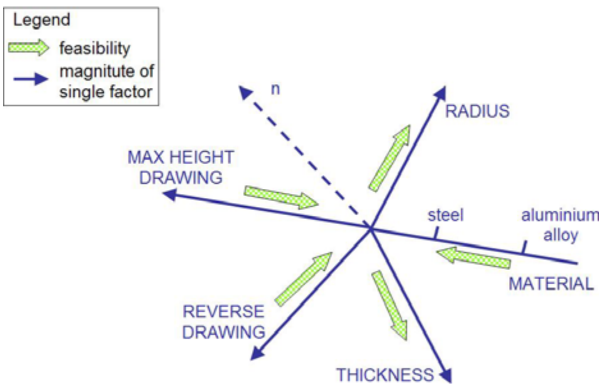

Figure 2: schematic feasibility space representation.

In this first schematic representation of each process variable a reference axis has been defined in order to understand the influence of its variation on the process feasibility which, in this case, is independent from the geometry profile. In order to be completely representative of the approached physical problem, this schematic representation has to be related to the specific geometry “producibile per idroformatura”. Any geometry can be characterized by a certain number “m” of adimensional shape factors. Then the feasibility space will change for the original n dimensions to the n+m dimensions due to the fact that in this case it is taken into account the formulation of the formed shape (Figure 3). In this case, the process feasibility is related to the specific shape factors for the given geometry. Authors have investigated which the possible adimensional shape factors needed to characterize the external panels components class are.

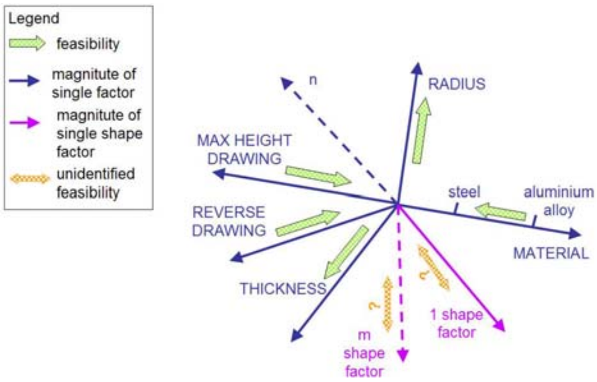

Figure 3: feasibility space for a specific component taking into account the proper shape factors.

The application of sheet hydroforming for external panels productions has already few remarkable industrial applications while on the contrary in the case of components for automotive fuel tanks this application looks like a very promising one because the most important automotive OEM (**O**riginal **E**quipment **M**anufacturing) is involved in specific research projects having as objective to promote the design and production of fuel tanks components through the plastic deformation of sheet metal panels **(** **S**trategic **Al**liance for **S**teel **F**uel **T**anks SASFT) [6]. Hydroforming could be a possible promising option, for this reason authors have considered also this class components in order to define appropriate shape factors.

SHAPE FACTORS DEFINITION

Having as reference the chosen industrial cases authors have proceeded with the shape factors definition in order to have adimensional coefficients representative for the given geometries.

Representative parts of the external panels "class" for automotive applications have been chosen, in particular two typical geometries were analyzed: a hood (Figure 4 and 5) and a fender components (Figure 6 and 7).

For each one of them appropriate adimensional parameters can be defined trying to correlate the maximum hydroforming depth with the most critical dimension of the original blank in top view.

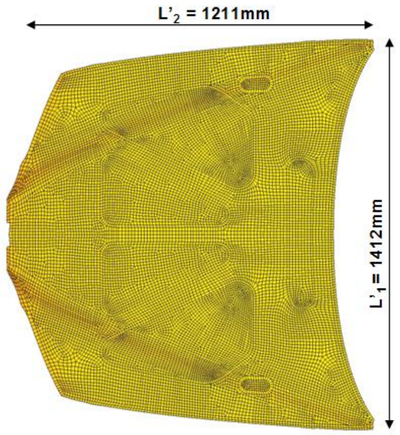

Figure 4: example of panel component: hood (top view).

Figure 5: example of panel component: hood (side section view).

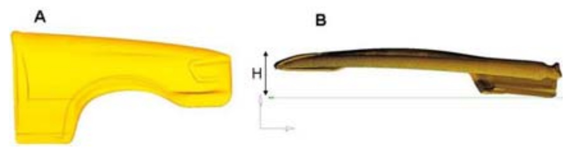

Figure 6: example of panel component, fender A: cad model (top view); B: FE model (side view).

Considering L_1' and L_2' (Figure 7) and H (Figure 6), you can define the following shape factor given from the ratio:

- $R_2 = L'_2 / H$ (where L'_2 is the smallest blank dimension in top view and H is maximum drawing depth).

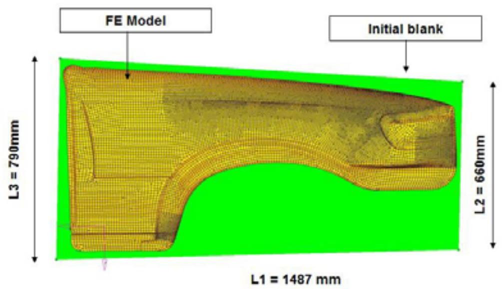

Figure 7: example of panel component: fender, top view of FE model and its initial blank.

The defined adimensional characteristic is only one of the possible ratios that can be useful to characterize a certain class of components.

In the case of components used for the fuel tanks construction, characteristic geometric elements have been also considered in order to define the relative shape factors. Elements such as redrawing height and top view dimensions were considered as significative

as well as the presence of more than one drawing depth in the same shape.
Thanks to these elements new shape factors have been defined:

- $R_h = L_2 / H_2$ (where L_2 is the minimum dimension of the blank in the top view related to the difference between two adjacent drawing heights, Figure 11 (b)).
- $R_c = L_c / H_c$ (where L_c is the maximum dimension in top view of a redrawing area and H_c is the maximum depth of this area).

Figure 8 illustrates some of the aspects which make the difference between a plastic fuel tank and a metal fuel tank. In the present production, upper and lower metal shells are realized separately after the forming operations the two parts are welded together. This process may lead to a high percentage of defected parts due to the bad quality of the welding process. This type of component can be produced thanks to sheet hydroforming avoiding the welding phase with some design reviews in comparison to the original geometry used for the plastic one [7].

Figure 8: from the plastic tank to the parted steel tank.

For a general component, obtained by hydroforming, it is possible to assume that its general sections could appear like the one reported in Figure 9. For this profile it's possible to apply the shape factors already defined:

- $R_2 = L_2/H = L_2/1$
- $R_h = L_2/H_2 = L_2/6$ or $L_2/2$, or $L_2/7$
- $R_c = L_c/H_c = 4/2$.

If it's possible to define more than one shape factor the most critical one in terms of its influence on the process feasibility will be considered.

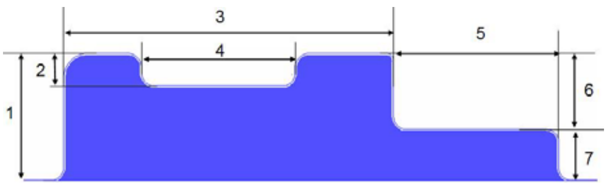

Figure 9: generic section shape for a sheet hydroformed component.

NUMERIC ADOPTED PROCEDURE

Equivalent geometric shape

The qualitative and quantitative analysis of the identified factors for the components classes taken into account will require a numerical-experimental activity which needs a relevant amount of resources if real parts geometries have to be investigated. For this reason similar but simpler components were chosen with the precise goal to reproduce the behavior of the defined real components, in order to use them for the numerical and experimental campaigns related to the "Process Performances" investigation.
Three reference models have been defined and named as MOD1, MOD2 and MOD5 as it is reported in Figure 10, 11 and 12, respectively. For each one of them it can be possible to identify the generic shape factors defined for the profile reported in Figure 9.

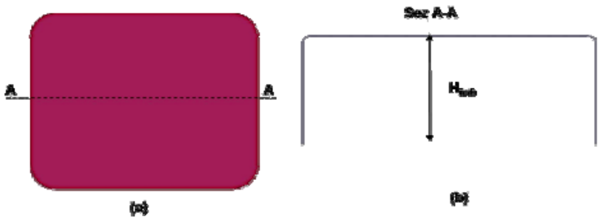

Figure 10: MOD1, shape factor definition. (a): top view, (b): section view.

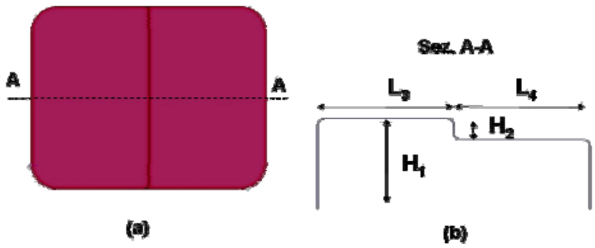

Figure 11: MOD2, shape factor definition. (a): top view, (b): section view.

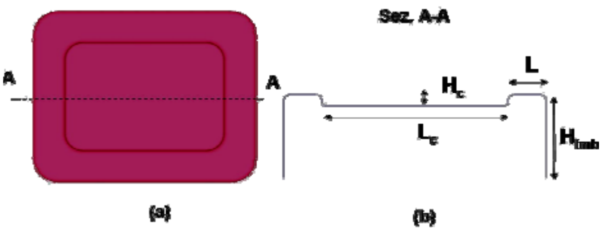

Figure 12: MOD5, shape factor definition. (a): top view, (b): section view.

Analysis of the equivalent shapes

For the given three models a numerical investigation has been developed in order to evaluate the influence of some geometric and process parameters on the process performance. Here the analyzed factors of each model are described:

TAB 1: MOD1's factors			
N° FACTOR	Name Factor	LEVELS	
		Lower Level (LL)	Upper Level (UL)
1	$H_{preforming}$ [mm]	15	45
2	Thickness [mm]	0.7	1
3	A1 [ton]	10	22.5
4	A2 [ton]	10	40
5	A3 [ton]	10	22.5
6	H_{imb} [mm]	100	150
7	R_p [mm]	10	50
8	R_m [mm]	10	20

where the Ai values are the blankholder forces applied by each actuator. In fact, in the developed models it has been considered a total number of twelve independent actuators which can be considered not all independent for the chosen shapes. For MOD1 and MOD5 due to the double symmetry of the models the independent actuators are just three while they become six for MOD2 where the geometry has just one symmetry plane.
$H_{preforming}$ is the value of the preforming height, H_{imb} is the maximum drawing depth, R_p and R_m are punch and die radius, respectively.

TAB 2: MOD2's factors.			
N° FACTOR	Name Factor	LEVELS	
		LL	UL
1	$H_{preforming}$ [mm]	15	45
2	Thickness [mm]	0.7	1
3	A1 [ton]	12	25
4	A2 [ton]	10	30
5	A3 [ton]	10	20
6	A4 [ton]	10	25
7	A5 [ton]	15	35
8	A6 [ton]	10	25
9	H_{imb} [mm]	100	150
10	H_2 [mm]	20	35
11	R_m [mm]	10	20
12	R_1 [mm]	10	50

For MOD2 and for MOD5, H_2 (Figure 11), R_1, and L (Figure 12) are added geometric parameter in order to fully define the geometry profile.

TAB 3: MOD5's factors.			
N° FACTOR	Name Factor	LEVELS	
		LL	UL
1	$H_{preforming}$ [mm]	15	45
2	Thickness [mm]	0.7	1
3	A1 [ton]	10	18
4	A2 [ton]	8	20
5	A3 [ton]	12	18
6	H_{imb} [mm]	100	150
7	H_2 ($H_{cavità}$) [mm]	20	30
8	L [mm]	65	130
9	R_p [mm]	10	25
10	R_m [mm]	10	20

For each given shape the appropriate metal forming set up has been developed for the different process conditions taken into account. Different process responses have been evaluated for each model. As example it is reported (Figures 13, 14) the FLD contour map and plot obtained for one of the considered process conditions related to MOD5.

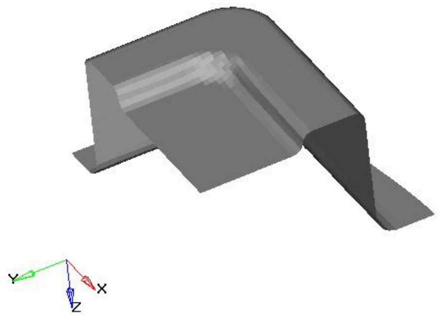

Figure 13: MOD5 hydroformed part, iso view.

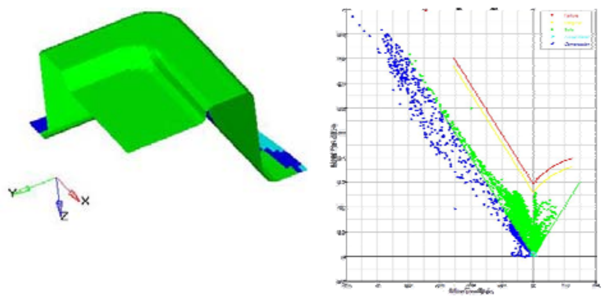

Figure 14: MOD5 hydroformed part, FLD contour map and plot.

In order to have a graphical immediate description of the interactions among the main factors of the sheet metal hydroforming, specific plots have been created in order to formalize the relationships between some of the process responses and some of the shape factors is reported in the case MOD1 (Figure 15) where it is reported the thickness reduction (%) trend having as independent variable the shape factor R_2.
For two different combinations of the thickness of the initial blank (0,7 mm and 1 mm) and constitutive material (low carbon steel FeP04 and aluminium alloy Al6061). The dimensions of the blank are always the same, the different depth drawing determines different R_2 values.

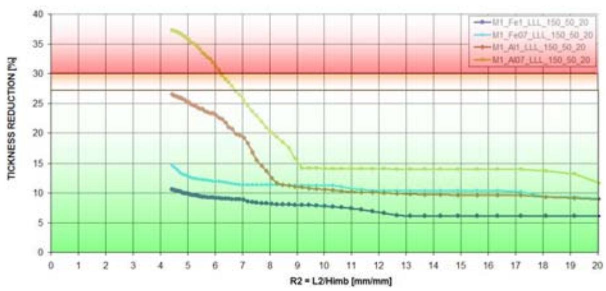

Figure 15: MOD1 first defined plot for process feasibility evaluation

Following the same philosophy in Figure 16 is reported the distance of the areas with maximum major strain in FLD (**F**orming **L**imit **D**iagram) from the FLC (**F**orming **L**imit **C**urve) versus R_2 parameter.

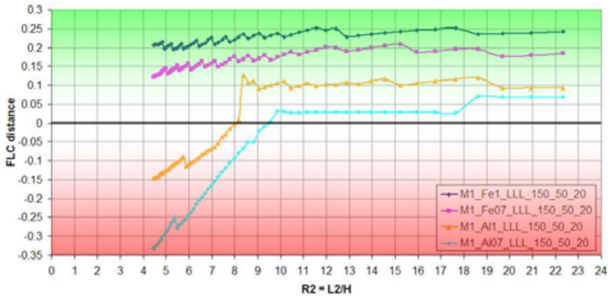

Figure 16: second graphic topology, for MOD1.

A coloured representation has been used in both cases in order to immediately identify the feasibility areas (the green ones).

CONCLUSIONS AND FURTHER DEVELOPMENTS

The defined plots reported in Figure 15 and 16 can be considered a significant aid for process feasibility definition for sheet metal forming. In fact, through their usage it is possible to find out the critical process parameters combination and to evaluate the safe or non safe margins of the obtained results in comparison to the solution/s suggested like the feasible one/s, according to the defined quality standards parameters. The defined diagrams are a first attempt to support process designers with effective solutions in order to understand the process performances for each designed configuration. At the same time, these diagrams can help to understand the robustness level of the implemented solutions.
The implemented shape factors give the chance to analyze, in a very early stage of the process development, the macro feasibility of a particular shape manufactured by a sheet metal hydroforming process.
In the next future, a specific experimental activity will be developed to validate the implemented procedure, taking advantage of the fact that a dedicated equipment has been assembled for this scope in accordance with the simulation set up developed for the different analyzed models (Figure 17).

Figure 17: hydroforming cell.

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