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Combining the pressure effect with local heat treatment for improving the sheet metal forming process

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Abstract. The present work deals with the advantages in the Hydromechanical Deep Drawing (HDD) when AA5754 Tailored Heat Treated Blanks (THTBs) are adopted. It is well known that the creation of a suitable distribution of material properties increases the process performance. When non heat-treatable alloys are considered, the THTB approach can be successfully applied to increase the Limit Drawing Ratio (LDR) by changing the peripheral zone into the annealed state starting from a cold-worked blank. If this approach is combined with the advantages of a counterpressure, even more remarkable improvements can be achieved. Due to the large number of involved parameters, the optimized design of both the local treatment and the pressure profile were investigated coupling an axial symmetric Finite Element model with the integration platform modeFRONTIER. Results confirmed the possibility of increasing the LDR from 2.0 (Deep Drawing using a blank in the annealed state) up to about 3.0 if combining the adoption of a THTB with the optimal pressure profile.

1. Introduction

The massive adoption of light alloys is becoming an unavoidable step for respecting the limitations of harmful emissions [1]. Aluminium (Al) alloys, which is a largely adopted light material, despite providing good resistance to weight ratio, present poor formability at room temperature: the adoption of such alloys thus needs deep investigations aimed at improving their attitude to be processed by stamping process. The Deep Drawing (DD) is considered an useful test to investigate such an aspect, since during the process the material undergoes a strain distribution similar to the one the blank experiences during industrial stamping processes. Several studies are reported in the literature about the possible solutions to increase the Limit Drawing Ratio (LDR), i.e. the ratio between the maximum blank diameter that can be fully drawn without rupture and the punch diameter: the adoption of a counterpressure during the DD process (Hydromechanical Deep Drawing, HDD) reduces the radial stress state in the cup wall and lowers the frictional forces in the flange region, thus having a beneficial effect [2]; an improvement can be also achieved adopting a suitable heating strategy during the stamping, for example heating the peripheral zone (lowering the yield stress and increasing the ductility) while maintaining the central region of the blank at room temperature (in order to have an high enough strength) [3]; a further strategy is to create such a local variation of material properties by means of a local heat treatments prior to the stamping process. The last approach is known as Tailored Heat Treated Blank (THTB) technology [4]. Even if plenty of researches exist concerning each of the abovementioned solutions to increase the LDR, only few works, and almost no one if the AA5xxx series is considered, investigate the advantages coming from the combination of the counterpressure with the THTB technology [5]. The present work deals with the numerical investigation of the improvement which the combination of the HDD and the THTB technology can produce. In particular, the aim is to design the local annealing treatment over the blank and, at the same time, define the optimal HDD process parameters (the pressure profile and the Blank Holder Force, BHF). Such a goal was obtained by means of a multi-objective optimization procedure which coupled an axial symmetric FE model with the integration platform modeFRONTIER.

2. The investigated alloy

The investigated material (AA5754) belongs to the group of the Al-Mg alloy, particularly suitable for automotive applications requiring high formability [6]. The mechanical behaviour was at first investigated in the annealed condition (red curve in Figure 1): tensile tests were conducted in order to determine the flow stress curve and to model it using the *Hollomon* equation ($\sigma = K\varepsilon^n$).

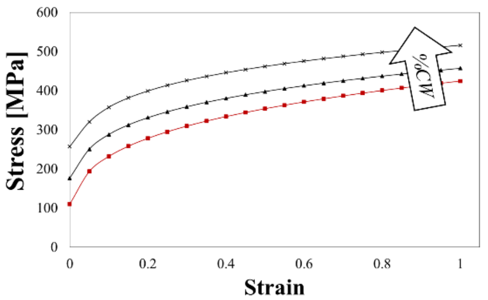


Figure 1. Flow stress curve as a function of *%CW*

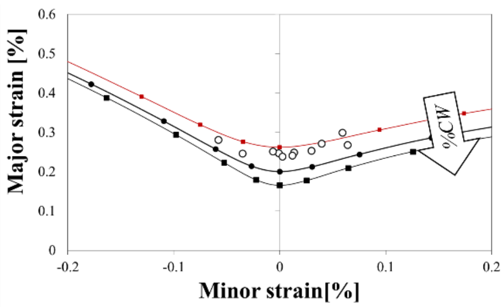


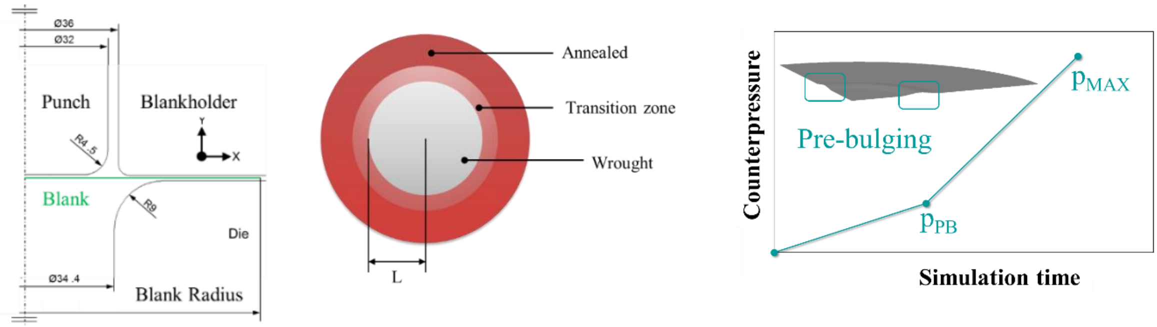
Figure 2. Comparison between the analytical and the experimental limit strains

Tests were also conducted on 5xxx alloys characterised by higher values of the cold-working (*%CW*): in such a way main mechanical parameters (yield stress, ultimate tensile strength and elongation at necking) could be modelled as a function of the parameter *%CW*. The deformative behaviour in the annealed condition was investigated by means of formability (Nakajima) tests. Tests were assisted by the non-contact Digital Image Correlation (DIC) GOM-ARAMIS system, able to acquire the strain distribution in the specimen. The experimental limit strains (white dots in Figure 2) were compared with the analytical Forming Limit Curve (FLC) calculated using flow stress data and the Modified Maximum Force Criterion (MMFC) [7]. Since a good overlapping between data was achieved, the MMFC was adopted to determine the FLCs of the investigated alloy corresponding to different values of the parameter *%CW*.

3. The numerical model and the optimization procedure

The axial symmetric numerical model in Figure 3a was created using the commercial FE code Abaqus. Tools were modelled as rigid bodies, while the blank (initial thickness 1 mm, radius variable in the range 36 - 50 mm) was deformable and meshed with 0.1 mm axisymmetric shell elements. The friction was modelled using the Coulomb law, setting the coefficient to 0.2 between the punch and the blank and to 0.05 between the blank and other tools [8]. The Von Mises yield criterion was adopted and material data described in the section 2 (in terms of both flow stress curves and FLCs) were implemented in the numerical model. The effect of the local heat treatment before the deformation was modelled setting different mechanical and deformative properties over the blank, as depicted in Figure 3b: the central part of the specimen, whose extension was managed by the parameter *L%* (it is a percentage of the radius), was modelled using material properties having a variable cold-worked condition (managed by the parameter *CW%*); the flange was always modelled in the annealed state; finally, in order to make the simulation more realistic, material properties were varied linearly (transition zone 1 mm wide) from the center to the flange.

In Figure 3c the pressure profile set in the HDD simulations is shown: it was designed in order to determine the bulging of the blank before the punch began its stroke; both the maximum pre-bulging pressure (p_{PB}) and the maximum forming pressure (p_{MAX}) were changed in the optimization loop.



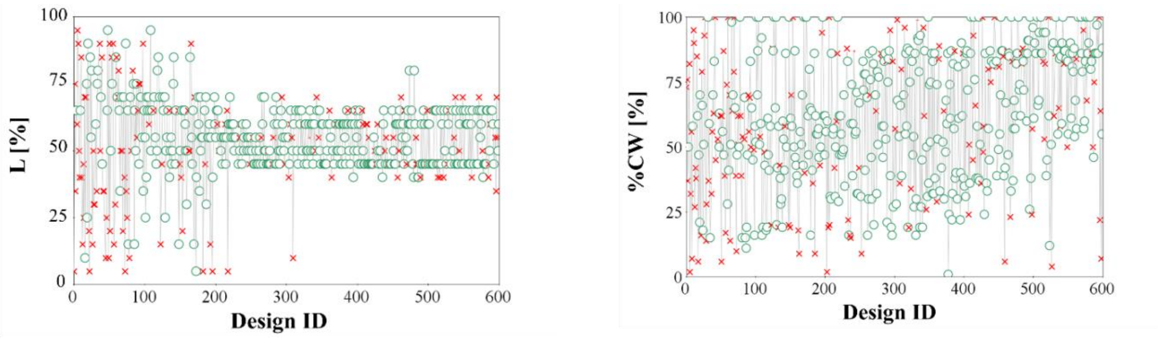
(a) (b) (c)

Figure 3. Process modelling: (a) 2D FE model; (b) distribution of material properties after the THTB; (c) pressure profile and parameters adopted for defining it

In fact, the FE model was coupled with the integration platform modeFRONTIER to carry out the optimization procedure based on a multi-objective genetic algorithm. The optimization was divided into 2 steps: in the first step, it was aimed at optimally distributing the mechanical properties over the blank (both the extension of the central blank region and the initial level of cold-working were evaluated); in the second step the pressure profile was optimized (the maximum pre-bulging pressure, the maximum forming pressure and the BHF were defined) while keeping fixed the heat treatment parameters. In particular, the second optimization step started from an initial population of 12 designs created with the Uniform Latin Hypercube algorithm [9] evolving through 20 successive generations. The objective functions in both the optimization steps were chosen to maximize the LDR and minimize the occurrence of blank rupture, monitoring the FLDCRT output variable (it is a standard output in Abaqus which takes into account how much the nodal strain is close to the Forming Limit Curve); in addition, to drive the optimization procedure toward significant results, constraints were applied to both the objective functions.

4. Results and discussions

In order to clearly describe the evolution of the input parameters during the optimization, *history charts* concerning the first optimization step are proposed in Figure 4.

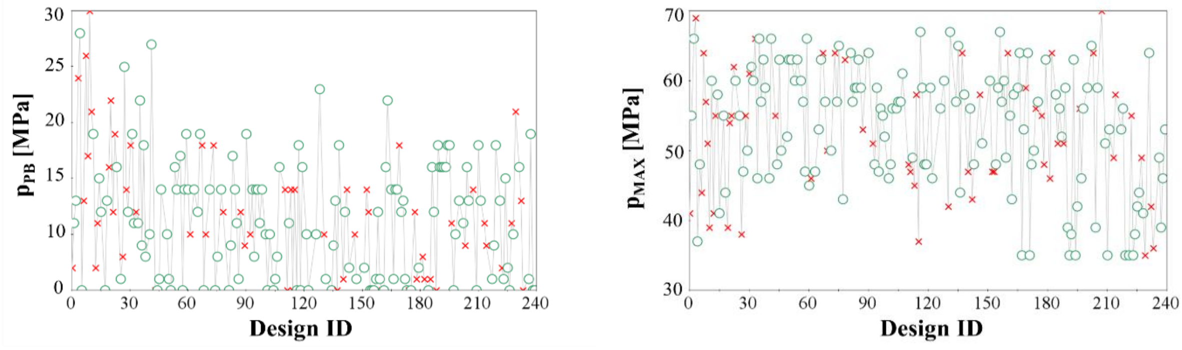


(a) (b)

Figure 4. Evolution of the values for parameters *L%* (a) and *CW%* (b) towards optimal values

In Figure 4 feasible designs (the designs respecting both the applied constraints) are indicated by empty circles, while the unfeasible ones by red crosses. The evolutions of both the parameters related to the heat treatment showed designs clusters within the last generations, highlighting that the region in contact with the punch needs a highly cold-worked condition (*%CW* about equal to 80%); at the

same time, the optimization results indicate that the annealing treatment has to be limited to the flange portion of the blank having the extension of about 35% (L% parameter tends to about 65%).
As concerning the second step optimization, *history charts* plotting the evolution of the pre-bulging pressure and the maximum forming pressure are shown in Figure 5.



(a) (b)

Figure 5. Evolution of the values for parameters p_{PB} (a) and p_{MAX} (b) towards optimal values

The graphs indicate that to successfully draw high values of the blank radius it is necessary to pre-strain the blank under a moderate bulging (around 10 MPa) and to increase the maximum pressure up to around 60 MPa during the deep drawing. The optimized distribution of the material properties combined to a properly designed pressure profile led to an achievable LDR value equal to 2.94 (R = 47 mm), which represents an improvement of +27% if compared to classical DD process. A key role in such a result is played by the local heat treatment: in fact, at the end of the first optimization step, the LDR was already increased up to 2.8 (21% higher than the classical DD process).

5. Conclusions

The improvement of the HDD process when THTBs are adopted has been numerically demonstrated using a two-steps multi-objective optimization. The first optimization step allowed to evaluate the maximum radius of the blank able to be successfully formed when adopting the proper level of the initial work-hardening of the central region and the proper extension of such an hardened region (LDR=2.8). The second optimization step allowed to determine the maximum radius of the blank able to be successfully formed when adopting the optimal pressure profile and BHF value (LDR=2.94). Thanks to the combination of the above mentioned techniques (local treatment and counter-pressure), the DD process can be improved even if performed at room temperature, thus needing a less complex equipment and leading to a consequent higher tool saving. Future developments will be aimed at refining the FE model and at validating its results by means of experimental tests.

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References

[1] Joost WJ 2012 *JOM*. **64** 1032
[2] Lang L, Li T, An D, Chi C, Nielsen KB, Danckert J 2009 *Mater. Sci. Eng.* A. **499** 320
[3] Palumbo G and Tricarico L 2007 *J. Mater. Process. Technol.* **184** 115.
[4] Geiger M, Merklein M, Vogt U 2009 *Prod. Eng.* **3** 401
[5] Piccininni A, Di Michele G, Palumbo G, Sorgente D, Tricarico L 2015 *Acta Metall. Sin. (English Lett.)* **28** 1482
[6] Hirsch J 2014 *Trans. Nonferrous Met. Soc. China* **24** 1995
[7] Mattiasson K, Sigvant M, Larsson M 2006 *IDDRG'06 Proceeding* Portugal.
[8] Halkaci HS, Turkoz M, Dilmec M 2014 *J. Mater. Process. Technol.* **214** 1638.
[9] Esteco, modeFRONTIER user manual v.4.5.3 2014