Journal of Computational Design and Engineering Vol. 1, No. 3 (2014) 187~193
www.jcde.org

Multicriteria shape design of a sheet contour in stamping

Fatima-Zahra Oujebbour[1,*], Abderrahmane Habbal[1,3], Rachid Ellaia[2] and Ziheng Zhao[1]

[1] *INRIA Sophia Antipolis, OPALE Project Team, 2004 Route des Lucioles, 06902 Sophia Antipolis, France*
[2] *Mohammed V - Agdal University, LERMA, Mohammadia School of Engineering, Rabat, Morocco*
[3] *University Nice Sophia Antipolis, Mathematics Dept, 28 Avenue de Valrose, 06103 Nice Cedex 2, France*

(Manuscript Received December 2, 2013; Revised March 8, 2014; Accepted May 12, 2014)

Abstract

One of the hottest challenges in automotive industry is related to weight reduction in sheet metal forming processes, in order to produce a high quality metal part with minimal material cost. Stamping is the most widely used sheet metal forming process; but its implementation comes with several fabrication flaws such as springback and failure. A global and simple approach to circumvent these unwanted process drawbacks consists in optimizing the initial blank shape with innovative methods. The aim of this paper is to introduce an efficient methodology to deal with complex, computationally expensive multicriteria optimization problems. Our approach is based on the combination of methods to capture the Pareto Front, approximate criteria (to save computational costs) and global optimizers. To illustrate the efficiency, we consider the stamping of an industrial workpiece as test-case. Our approach is applied to the springback and failure criteria. To optimize these two criteria, a global optimization algorithm was chosen. It is the Simulated Annealing algorithm hybridized with the Simultaneous Perturbation Stochastic Approximation in order to gain in time and in precision. The multicriteria problems amounts to the capture of the Pareto Front associated to the two criteria. Normal Boundary Intersection and Normalized Normal Constraint Method are considered for generating a set of Pareto-optimal solutions with the characteristic of uniform distribution of front points. The computational results are compared to those obtained with the well-known Non-dominated Sorting Genetic Algorithm II. The results show that our proposed approach is efficient to deal with the multicriteria shape optimization of highly non-linear mechanical systems.

Keywords: Sheet metal forming; Initial blank shape; Springback; Failure; Multi-objective optimization

1. Introduction

The sheet metal forming is of vital importance to a large range of industries as production of car bodies, cans, appliances, etc. It generates complex, of high geometrical precision, parts. However, the associated production technologies involve mechanical phenomena combining elastic-plastic bending and stretch deformation of the workpiece. These deformations can lead to undesirable problems in the target shape and performance of the stamped. To perform a successful stamping process and avoid the unwanted springback and failure defects, process variables should be optimized.

One of the most important issue in stamping process concerns initial blank shape optimization that can reduce if not eliminate design problems of the obtained product [1-5].

In general practice, techniques that are used in this optimization process were based on experiments and trial and error method which induce very high costs. Nowadays, growth and advances in computer science technologies are proved and numerical simulation tools are an efficient alternative, mainly making recourse to the finite element method (FEM).

In this context, several studies had been done to optimize forming parameters such as punch speed, blank holder force, friction coefficient, etc. [5-7]. Others investigated the optimization of geometrical parameters such as the radii of the punch and the die, the binder surface, etc [8, 9]. More recently, some studies were performed for the design optimization of tools in order to reduce the design time but without considering the quality of the desired workpiece [10].

We aim here to develop a numerical tool for the shape optimization of an initial blank in order to reduce springback and risk of failure. More precisely, the application targeted by this article is to efficiently optimize the initial blank shape used in the stamping of an industrial workpiece stamped with a cross punch, as presented in section 4. The stamping process is performed using the commercial FEA code LS-DYNA. The criteria considered are springback and failure. These two phenomena are the most common problems in the stamping process, and they present many difficulties in optimization since they are two conflicting objectives. To solve

*Corresponding author. Tel.: +33 (0) 6 59 59 28 30
E-mail address: fatima.oujebbour@inria.fr; oujebbourfatimazahra@gmail.com

doi: 10.7315/JCDE.2014.018

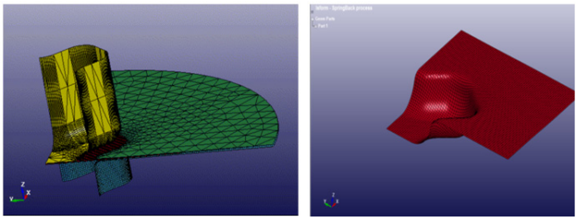

Figure 1. Simulation of stamping process (LS-DYNA).

Table 1. Process parameters used in simulation.

Process Parameter	Value
Material	HSLA260
Young's modulus	196GPa
Poisson's ratio	0.307
Density	7750Kg/m^3
Hardening coefficient	0.957
Punch speed	5m/s
Punch stroke	30mm
Blanck holder effort	79250N
Friction coefficient	0.125
Number of elements	5775

each single objective optimization problem, the approach chosen in section 5.1 was based on the hybridization of a heuristic algorithm, the Simulated Annealing (SA) [11], and a direct descent method, the Simultaneous Perturbation Stochastic Approximation (SPSA) [12]. This hybridization is designed to take advantage from both disciplines, stochastic and deterministic, in order to improve the robustness and the efficiency of the hybrid algorithm. For the solution of the multi-objective problem, we adopt methods based on the identification of Pareto front.

To have a compromise between the convergence towards the front and the manner in which the solutions are distributed, we choose two appropriate methods in section 5.2 which are the Normal Boundary Intersection (NBI) [13] and The Normalized Normal Constraint Method (NNCM) [14]. These methods have the capability to capture the Pareto front and have the advantage of generating a set of Pareto-optimal solutions uniformly distributed. The last property is of important and practical use in the multicriteria optimization of non-linear mechanical systems. By reformulating the multi-objective problem to single-objective sub-problems and only with few points, these two methods can form a uniform distribution of Pareto-optimal solutions, which can help the designers and decision makers to select efficient solutions among the well represented Pareto front in the design space.

It is important to notice the necessity of solving the single-objective sub-problems with global optimization approaches whereby we can obtain a global Pareto front, whereas the resulting optima using a gradient-based local optimization algorithm are only local Pareto-optimal solutions.

To check the efficiency of these multi-objective approaches, numerical examples were used to compare the obtained results with those obtained with a well-established technique in multi-objective optimization called Non-dominated Sorting Genetic Algorithm II (NSGAII) [15]. The results of initial blank shape optimization of the investigated test case, in order to reduce the springback and the risk of failure, were done, and are presented in the end of this section. Finally, a conclusion and perspective views are provided in Section 7.

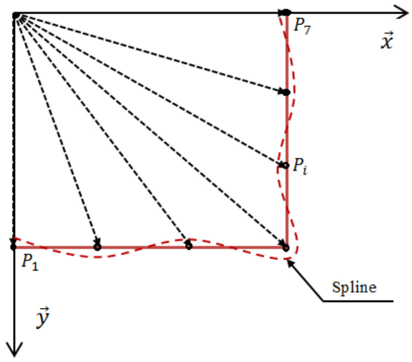

Figure 2. Blank contour parameterization.

2. Finite element modelling

Numerical simulation of metal forming processes is currently one of the most used technological innovations, which aim to reduce the high tooling costs, and facilitates the analysis and solution of problems related to the process.

In this study, the FEA code, LS-DYNA, was used to model and compute the stamping of an industrial workpiece. LS-DYNA is an explicit and implicit Finite Element program dedicated to the analysis of highly non-linear physical phenomena.

The aim was to study the influence of the initial blank shape on the stamping process of a blank with a cross punch (Figure 1). The blank was made of high-strength low-alloy steel (HSLA260) and was modelled using Belytschko-Tsay shell elements, with full integration points.

Due to symmetry, only the quarter of the blank, die, punch and blank holder were modelled and symmetric boundary conditions were applied along the boundary planes. Mechanical properties of materials and process characteristics are shown in Table 1.

3. Problem description

A sensitivity analysis done using FEA demonstrated that the overall dimensional quality is highly influenced by the initial dimensions of the blank. The initial blank design is a critical step in stamping design procedure; therefore it should be correctly designed.

This study aims to find the optimal initial blank shape that satisfies the design specifications during the forming process. To meet these specifications, it is mandatory to eliminate or at least minimize springback and risk of failure problems.

For this study, the geometry of the blank contour is de-