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Experimental and numerical optimisation of the sheet products geometry using response surface methodology

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Abstract

In this paper, two types of shapes were retained in order to investigate the behaviour of automotive safety parts that are obtained by successive sequences of blanking and bending. Firstly, experiments have been conducted in press tools for a sufficient number of process parameters combinations, particularly, die radius and clearance. Design of experiments and response surface methodology (RSM) were adopted to plot results obtained using the two-specimen geometries. Secondly, numerical model based on elastic plastic theory and ductile damage has been developed for the prediction of material behaviour during forming. The numerical approach was applied to study the mechanical responses of bent parts obtained by using each specimen shapes. The same parameters used for conducting experiments were retained for numerical simulation. However, the maximum bending load obtained for the two investigated cases were treated by application of response surface method. The damage values show a clear difference between the two considered specimen shapes. Numerical bending results compared to experimental values show the reliability of the proposed model for each case. The effects of geometry parameters on the bent parts and convenience of the obtained graphics were discussed in details.

Keywords: Steels; Design of experiments; Simulation; Damage; RSM

1. Introduction

Most sheet steels commonly used in automotive and other manufacturing applications have high properties, such as ductility, resistance and Young's modulus. These materials can be bent under very severe parameters without fracture or cracking. In a pioneer works [1], it has been laid down that the final mechanical characteristics of parts do not depend only in material properties but also in the geometry retained for producing workpieces.

The optimisation of forming processes aimed to the production of net-shape components and high resistant products is nowadays one of the fundamental topics on which the interest of automotive research groups is focused.

Several contributions [2–5] have been conducted in order to reduce stretching and springback phenomena by combining process parameters and sometimes by the choice of materials type having good properties, whereas, works treating the effect of geometry in the final mechanical state of product remain nowadays insufficient.

As a preferment procedure, response surface technique is retained in several cases for treating and then, for predicting sheet metal forming problems. It is a useful engineering method to analyse and to supervise the mechanical and geometrical behaviour of workpieces, such as bent parts.

Todoroki and Ishikawa [6] have described in their works a new experimental method to optimise stacking sequence by applying a response surface method to composite cylinder products.

Unfortunately, the two-dimensional plot still limited to overcome all understanding difficulties and remains far from the required fine model that can describes problems accurately. In addition, it is a consuming time to use because it is unable to present results versus more than one variable.

Similarly, Chou and Hung [7] have used the response surface technique for analysing springback that they have taken as a function of both material properties and tools parameters. However, extensive works [8] has adopted the same procedure for optimisation of vehicle crashworthiness design. Several

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functional evaluations may be needed for solving this kind of problems.

Therefore, the diversification of consumer needs lead to the changes from mass production to small quantity in which geometry is mostly different. Hence, the reduction of time for product design is crucial. The response surface technique is showed to be so reliable to solve the problem not only from a practical point of view but also by adopting a numerical simulation strategy.

In the way of the response surface method application, Ohata et al. [9] have developed an optimum design system to assist the decision of material process condition for making best sheet formability for stamping. They combined finite element analysis and discretised optimisation algorithms for this purpose. The response surface method has been applied in order to attempt search the optimum conditions quickly and to help for deciding a sheet forming process.

Optimisation of the process by classical methods based on empirical rule adjustments is not usually applicable to complex geometries or materials without a large database of experience. It involves changing one independent variable of the problem while all others are a fixed level [10,11]. This is extremely time-consuming and expensive for a large number of variables. To overcome this difficulty, factorial design of experiments and response surface methodology can be employed to optimise medium components [12–15].

In this work, comparison between experiments and simulation has been carried out for deciding suitable process parameters in bending operation. The initial shape of sheet specimens is chosen in such a manner that the bent section would be the same for the two cases and representative as soon as possible of the real geometry of safety parts. The first specimen consists in an oblong-hole at the bent section whereas the second is a full-section specimen.

Experimental and numerical results are conducted for an extensive combination of die radius values and punch–blank clearance values. The maximum bending load and maximum damage were plotted by applying the response surface technique allowing a reliable prediction of parameters that avoid the appearing of fracture or cracking in bent product.

2. Design procedure

2.1. Experimental approach

Sheet metal bending processes are widely used for mass production. In spite of their cost and their consuming time, experimental procedures still yet crucial to prove reliability of such model or formulation. Especially, experiment data are required to establish the objective function for an optimisation concept. The response surface methodology depends strongly on the measurement accuracy.

In order to obtain suitable process parameters for specific bending condition, a method has been laid down for initial sheet design by an extended experimental study based on varying the clearance and the die radius.

Lubrication is retained for all tests and, bending force is recorded for each design variables combination thanks to cell load and acquisition equipment. The considered steel is 4-mm thickness H.S.L.A. sheet material. The cut specimens used to examine the geometry effect on the strength of bent parts are given in Fig. 1.

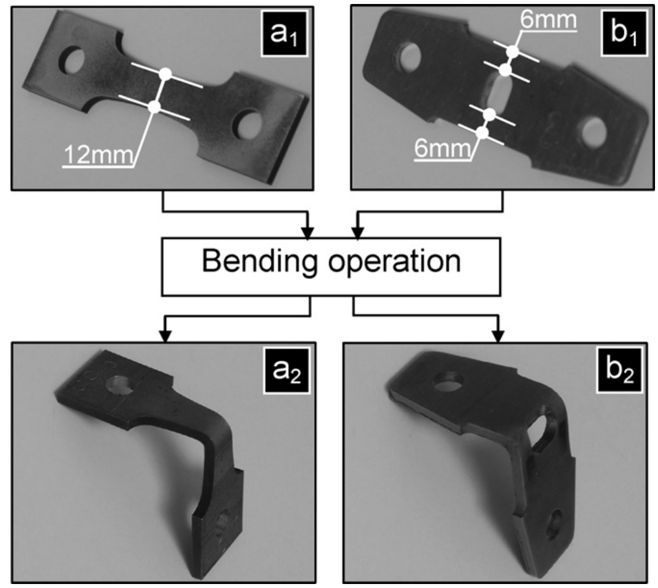

Fig. 1. Initial (a_1 and b_1) and final (a_2 and b_2) steps of bending tests.

The experimental procedure has need 21 cases of tests in press tools. All parameters combinations are reported in the following Table 1. Although, much progress has been achieved for improved experimental strategy of sheet bending, there are yet still needs for further advancing the existing methods, in particular, for verifying the reliability of numerical models.

This analysis consists, firstly, in an examination of the final state of the wiping-die bent sheet by adopting an experimental

Table 1
Experimental combinations considered for bending tests

$H_G = D_R/\varepsilon_R - \varepsilon_D$	Die radius/thickness: $\bar{R}_d = R_d/t$	Clearance/thickness: $\bar{J} = J/t$
0.596	0.5	−0.15
0.596	0.5	−0.10
0.596	0.5	−0.05
0.596	0.5	0.00
0.596	0.5	0.05
0.596	0.5	0.10
0.596	0.5	0.15
0.596	1.0	−0.15
0.596	1.0	−0.10
0.596	1.0	−0.05
0.596	1.0	0.00
0.596	1.0	0.05
0.596	1.0	0.10
0.596	1.0	0.15
0.596	1.5	−0.15
0.596	1.5	−0.10
0.596	1.5	−0.05
0.596	1.5	0.00
0.596	1.5	0.05
0.596	1.5	0.10
0.596	1.5	0.15