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The Role of Evolutive Elastic Properties in the Performance of a Sheet Formed Spring Applied in Multimedia Car Industry

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Abstract. The manufacturing process and the behaviour of a spring manufactured from an aluminium sheet is described and investigated in this work considering the specifications for the in-service conditions. The spring is intended to be applied in car multimedia industry to replace bolted connections. Among others, are investigated the roles of the constitutive parameters and the hypothesis of evolutive elastic properties with the plastic work in the multi-step forming process and in working conditions.

1. Introduction
The competitiveness of the automotive industry has led to a simultaneous increase of innovative design concepts, lightweight materials and a more efficient costs control. The present study aims to investigate an innovative solution for fixing a printed circuit board (PCB) under a metallic chassis (sheet metal parts) without bolted connections. This geometry must be capable of submitting the PCB under a compressive load, to ensure the ground contact between components. The finite element analysis (FEA) has been widely used by scientific and industrial communities in product design and to predict material’s behaviour. FEA reduces the number of trials, reducing the cost of product development [1-2]. The problem investigated in this paper is to evaluate the usage of a new spring to replace bolted connections. The research objectives are to evaluate the effects of the manufacturing process, the evolution of the elastic properties due to the plastic work, and the hardening models.

2. The new spring: geometry description
The proposed geometry (Figure 1) is located at the cover corners of a metallic chassis. It consists in a recess with a trapezium format where the contact between the PCB and chassis will occur. The innovation presented in this geometry is focused on the geometry around the recess. This geometry consists of material removal in the shape of tabs and it was designed to have a similar behaviour to a spring. The geometry was subject of previous numerical simulations aiming to find the best geometry’s shape to the tabs.

![Figure 1. Developed geometry to replace bolts: its placement in the chassis top cover (left), and detailed geometry of the spring (right).](image)

3. Numerical modelling
3.1. DD3IMP
Deep Drawing 3D IMPllicit Code (DD3IMP) is a finite element (FE) code which is the result from continuous development and optimizations aimed for the simulation of sheet metal forming processes.
This 3-D elastoplastic FE code allows large elastoplastic strains and rotations, following a fully implicit time integration scheme. DD3IMP models the geometry of the forming tools by parametric Bézier surfaces or Nagata patches [5]. The frictional contact between the two bodies is interpreted with a classical Coulomb’s law with an augmented Lagrangian approach. The frictional contact algorithm operates directly on the parametric Bézier surfaces or the Nagata patches [6].

3.2. Constitutive Models

The efforts done by scientific community to improve and create new constitutive models in FE are now providing a more efficient description of the mechanical behaviour of sheet metals [7]. The orthotropic yield criterion is currently used to model the planar anisotropy of the blank. In turn, the isotropic and kinematic hardenings describe the evolution of the flow stress and the yield surface with the plastic work.

In the present work it is used a Voce law to describe the isotropic work hardening. Kinematic hardening is computed by Lemaître & Chaboche evolution law. It is intended to manufacture the multimedia system chassis in aluminium alloy, in the grade AA5182-O [7]. This specific material has constitutive parameters to be used in Voce law [eq. (1)] and in evolution law [eq. (2)]:

\[
\begin{align*}
Y &= 148.5 + 192.4\{1 - \exp(-9.7 \, \bar{\varepsilon}^P)\} \\
\bar{X} &= 152.7\left[\frac{26.0}{\bar{\sigma}} (\sigma' - X) - \bar{X}\right] \bar{\varepsilon}^P, \quad X(0) = 0
\end{align*}
\]  

where \(\bar{\varepsilon}^P\) is the equivalent plastic strain, \(Y\) is the flow stress, \(X\) the back stress tensor, \(\sigma'\) the deviatoric Cauchy stress tensor and \(\bar{\sigma}\) the equivalent tensile stress of the isotropic von Mises yield criterion.

3.3. Elastic properties evolution

Most studies of sheet metal forming consider the elastic behaviour as isotropic and constant, assuming that plastic work has no effect in the elastic properties. It is considered that when a permanent plastic deformation takes place, the elastic strain will be recovered. Presently the accuracy of each study is defined through the mathematical models implemented and depends on the studied case. Alves et al. [10] point out that for some materials, taking into account the evolutionary isotropic elasticity can have a larger effect on springback prediction than taking into account the kinematic hardening.

In the present study, only macroscopic evaluations will be considered. The evolution of Young modulus as a function of the plastic strain is given throughout the law proposal by Alves et al. [10]. This law is based on the experimental work of Yang et Al [8,9], who proposed an evolution law based on experimental measurements given by a polynomial equation, however its interval of validity is restricted to less than 25% of plastic strain. In sheet metal forming the maximum equivalent plastic strain is usually higher than 25%. Because of that, Alves et al. [10] introduced an exponential equation with saturation which describes better the evolution of the elastic properties in a wider range of plastic strains. The evolution law was implemented in DD3IMP FE code and it is given in a generic form by:

\[
E = E_0 + k_E . E_0 \{1 - \exp(-C_E \bar{\varepsilon}^P)\}
\]  

where \(E_0\) is the value of the initial Young modulus, \(k_E\) and \(C_E\) are the parameters of the evolution law and \(\bar{\varepsilon}^P\) is the equivalent plastic strain. \(k_E \in [0,1]\) defines the saturation value of the Young modulus, \(\lim_{\bar{\varepsilon}^P \to +\infty} \left(\frac{E_0 - E(\bar{\varepsilon}^P)}{E_0}\right) = k_E\), and \(C_E\) measures the rate of approximation to the saturation value.

4. Numerical results

4.1. Simulation Setup

The numerical study was separated in two main stages. In the first stage the stamping process was numerically simulated. This process is responsible for the major geometrical changes and plastic work field in the raw sheet metal. In the first step a blank sheet with a rectangular shape of 30 mm x 30 mm x 1.2 mm is positioned between the holder and the die. A fixed clearance is imposed between the
holder and the die during all the punch displacement. The punch moves vertically giving shape to the sheet metal, and when the punch meets to the final position it moves back in the opposite direction, allowing the springback of formed part. The second stage simulates the operating conditions of the proposed geometry, in order to investigate the role of the evolutive elastic properties on the mechanical behaviour of the spring. The spring is loaded by a tool representing the PCB. As boundary conditions, a displacement of 1 mm is imposed to the tool, and the reaction force is evaluated.

In order to compare the role of either constitutive models, two main types of numerical simulations were carried out using the same boundary conditions and FE meshes. The first group only considers the assembly conditions (AC label) during the assembly of the cover in the chassis, which corresponds to pressing the spring. The second group considers all the forming history since manufacturing process (MP label) until assembly conditions (MP.AC). For each of these groups, different material laws are used. For example, “MP.AC.EPE.KH” is a simulation in which all conditions are activated, including evolutive elastic properties (EPE) and kinematic hardening (KH).

4.2. Results and discussion

To evaluate the influence of elastic properties evolution and kinematic hardening in numerical simulation of assembly conditions (AC), Figure 2 (a) shows the force reaction along a 1 mm displacement in four different cases. The four simulations were conducted taking into account the following phenomena: with only elastic properties evolution (AC.EPE), with only kinematic hardening (AC.KH), with both phenomena (AC.EPE.KH) and without any of them (AC).

![Figure 2. Curve force versus displacement during the simulations of the assembling process.](image)

In Figure 2 (a), the MP condition is not activated, i.e. the forming history is not taken into account. In this case, the material of the spring is considered as new material without any plastic work history. The AC and AC.EPE curves show a very similar behaviour. It allows concluding that elastic properties evolution does not influence the spring behaviour. When kinematic hardening was considered, the maximum force values for the same displacement of the tool (or the PCB) is lower. The evolution of the elastic properties, i.e. of the value of the Young modulus with the plastic work has almost no influence. For the four cases on Figure 2 (a), the equivalent plastic strain is consistently low, and it occurs in well-defined zones. There is no substantial difference in the maximum plastic strain amongst the four different studied cases. In the case where the material does not consider Bauschinger effect (i.e. there is not kinematic hardening) and the elastic properties evolution, the force required to perform the same displacement is about 5% higher. When the evolution of Young modulus and the Bauschinger effect are considered, the maximum force is lower.

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Figure 2 (c) indicates that there is a non-negligible difference between AC and MP.AC. For about 0.4 mm displacement the difference between the curves is of 22%, but AC.EPE.KH curve starts to saturate earlier and, at the end of 1 mm displacement, the MP.AC.EPE.KH displays a higher maximum force. The difference between the maximum force values at the end of displacement is of 3%. The maximum plastic strain takes place during the manufacturing process stage as expected. When compared with the first stage, the plastic work caused by the remaining steps is too low. In the...
remaining steps, deformation is concentrated in the extremities of the tabs, and mostly in the elastic regime. Figure 3 shows a comparison between the equivalent plastic strain of the cases in Figure 2 (c).

![Figure 3. Comparison between the equivalent plastic strain field of the AC.EPE.KH and MP.AC.EPE.KH simulation.](image)

5. Conclusions
The study of the mechanical behaviour and manufacturing process of a new spring to be applied in car multimedia industry was presented. The role of both constitutive modelling and evolutive elastic properties was analysed in order to determine their in-service conditions and specifications. The new spring is intended to replace several bolted connections, and thus the spring forces plays a paramount role. The analysis of the numerical results presented in the previous figures allow to conclude:

- For the investigated cases where the equivalent plastic strain is low, the evolution of the elastic properties, due to the plastic deformation, has almost no influence in the behaviour of the spring;
- The description of the Bauschinger effect (kinematic hardening) has shown different values due to cyclic loadings, and direction changes that the investigated geometry was submitted.
- The study of loading history (manufacturing process) is important to obtain reliable results during assembling and working conditions. The effect of pre-deformation on the geometry behaviour occurs, likely, due to the change of the elastic behaviour of the material. Neglecting the loading history of the material can lead to wrong predictions concerning the spring’s behaviour;
- The scientific community has been shown the importance of kinematic hardening and elastic evolution properties in springback prediction of sheet metal parts. This study shows that, the loading history and evolutive elastic properties are more important than the kinematic hardening;
- Finally, a correct description of features of the mechanical behaviour has an enormous importance to accurately predict the performance of a sheet metal formed part.

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