Numerical Simulation of Sheet Metal Bending with Deformable Pads Made of Reinforced Silicon Rubbers

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This paper presents a numerical simulation for metal sheet bending with elastic pads made of silicone rubber reinforced with different ratios of very small glass fibers. Experimental tests were performed (traction and compression), in order to determine some characteristics for the materials and the results were used in the simulation program. A correction for the geometry of the punch, a prediction diagram for springback angle and the evolution of the force developed by the punch are also presented

Keywords: numerical simultation, silicon rubber, glass fibers, finite elements

Bending with elastic tools is a method based on replacing one half of the forming tool, either the punch or the die, by a pad of rubberlike materials. Using an elastic punch proved to be difficult to realize and the benefits were minimum, so the technology based on elastic pads developed mostly.

Usually a rubber pad of approximately 80-90 Shore A hardness is used [4] in order to have a high pressure upon the sheet material. This is proper for the precision of the parts but also need high energy consumption for bending. The problem that appeared from this observation is to diminish the compression stress for the elastic pad in order to have lower energy consumption but also a good precision for the part.

The principle of such a forming procedure is shown in figure 1. One may notice that the standard bending die has been replaced by a deformable pad. During the descending motion of the press slide, the blank is gradually bent over the rigid punch by the pressure developed at the interface with the rubber pad. In general, the tools working on the basis of the principle shown in figure 1 are less expensive than the classical bending dies. Such tools can be easily adapted to the manufacturing of parts with different shapes and dimensions by replacing only the punch. Due to the deformable pad, the stroke adjustment does not involve any change in the construction of the die. And last but not least, the springback compensation of the bent part is less difficult (in general, only the punch profile must be altered).

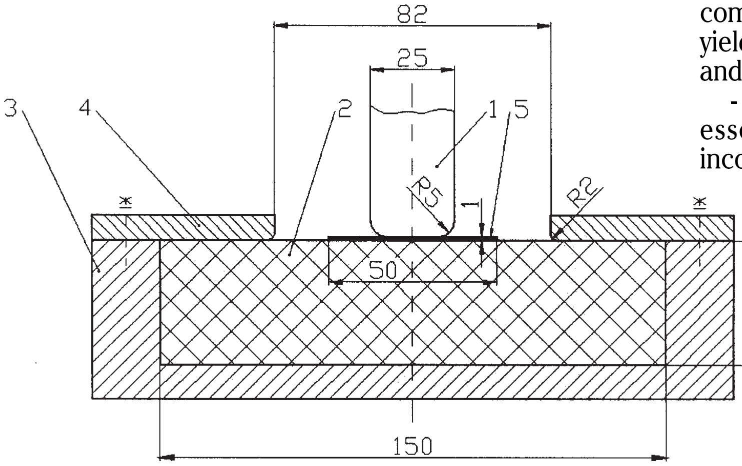

Fig. 1. Dimensions of the tools and metallic blank used in the simulation of the bending process (1 – punch, 2 – deformable pad, 3 – container, 4 – retaining plate, 5 – blank)

Simulation program

The numerical tests presented below aim to evaluate the technological performances of the elastic materials when used as deformable pads in the structure of a sheet metal bending die. Figure 1 shows the dimensions of the tools and metallic blank used in the simulation model. The bending process is assumed to evolve under plane-strain conditions. This hypothesis is fully justified by the fact that the blank width (50 mm – dimension perpendicular to the plane of the sketch shown in figure 1) is sufficiently large as compared to the sheet thickness (1 mm). Because of the bilateral symmetry of the bending process, the simulation model can be reduced to half of the planar section.

The numerical tests have been performed using the finite-element program Abaqus/Explicit [1, 2]. Besides the plane-strain assumption, the following hypotheses are also adopted by the simulation model:

- the metallic components of the die (punch, container and retaining plate) have negligible distortions during the bending process. As a consequence, they can be treated as rigid bodies. Due to the two-dimensional character of the simulation model, the geometric description of the punch, container and retaining plate reduces to those segments of their curvilinear boundaries which are candidates to getting into contact either with the blank or the deformable pad.
- the mechanical response of the blank is elastoplastic. The elastic component of this behaviour is defined by the standard Hooke law [1, 2]. As concerns the plastic component, its description is provided by the von Mises yield criterion combined with an isotropic hardening law and the associated flow rule [1, 2];
- the mechanical response of the deformable pad is essentially hyperelastic and can be described by an incompressible neo-Hooke law [1, 2];

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- the contact interaction between the blank, deformable pad and rigid tools has a frictional component described by a Coulomb model [1, 2];
- the container and the retaining plate are fixed, while the punch performs a descending/ascending motion with zero acceleration at the ends of the stroke.

The curvilinear boundaries of the punch, container and retaining plate have been defined using an analytical description. In the case of the rigid bodies having simple configurations, the analytical description provides a better accuracy of the contact models. The cross-sections of the blank and deformable pad have been meshed using 4-node quadrilateral elements with reduced integration and standard hourglass control [1].

Experimental part

In order to perform the numerical simulation, the materials used for bending and for elastic pads must be tested. The metal sheet is tested on traction and the materials for elastic pad on compression.

The blank material is an AlMgSi1 aluminum alloy. Its elastoplastic constitutive model has been calibrated using the values of Young's modulus E = 64670 [MPa] and Poisson's ratio $\nu = 0.33$, as well as a tabular description of the hardening law shown in figure 2. The main mechanical parameters (fracture strength, conventional flowing strength, elasticity modulus, fracture elongation, strain hardness coefficient, anisotropy coefficient), are presented in literature [3].

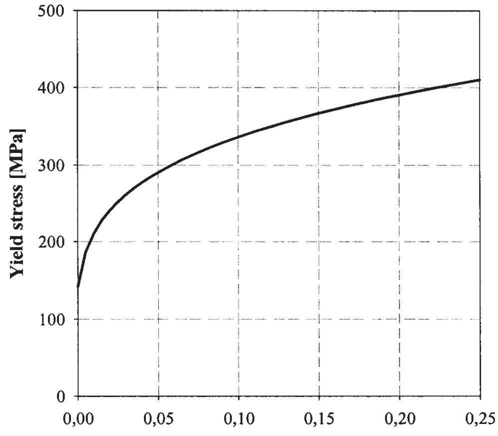


Fig. 2. Hardening curve of the AlMgSi1 sheet metal (1 mm thickness)

The samples for the material used for elastic pad were fabricated out of a composite material made of silicone rubber, mixed with very short and discontinuous glass fibers (whiskers), with the purpose of reinforcement. The dimensions of the samples were established according to SR ISO 815-A1:1995, under the form of a circular disk with a diameter of 29.0 ± 0.5mm and a width of 13.0 ± 0.2 mm. As a basic material, two types of silicone rubbers, namely: the Essil 291 type, with a hardness of 50 IRHD (≈ 36 Shore A1) and Essil 125, with a hardness of 34 IRHD (≈24 Shore A1), were used. Very short glass fibbers used for reinforcement are in the following proportions: 5, 10, 15 and respectively, 20% [5-7].

The fabrication of the samples follows the usual steps. The homogeneity of the material was realized by mixing the silicone rubber with glass fibber and the catalytic agent was added only at the end. The material was degassed by using vacuum at a pressure of -105N/m^2 in order to eliminate all the air holes from the interior. After the mixture was poured in the mould, the material was degassed for the second time. The polymerization was made into an oven at 45°C for 24 h.

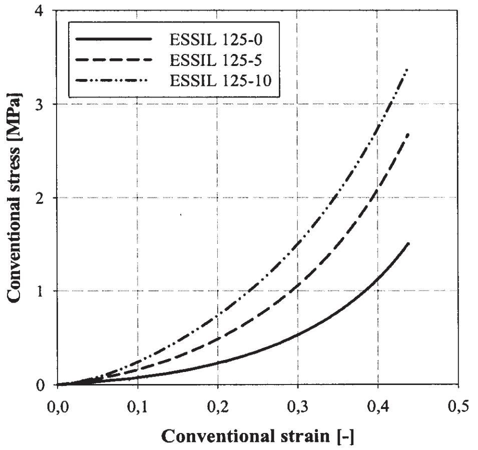


Fig. 3. Compression curves for ESIL 125

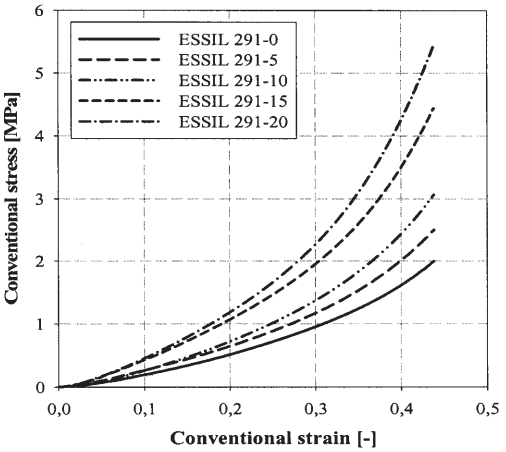


Fig. 4. Compression curves for ESIL 291

The mechanical characteristics for the materials are determined through the compression test on a normalized specimen. The hyperelastic constitutive model associated to the deformable pad has been calibrated using a tabular description of the experimental curve defining the relationship between the conventional stress and strains in simple compression. The results for compression stress due to compression strain are presented in figure 3 and 4.

The samples were compressed on a Zwick/Roel Materials testing machine Z150 with test Control PC and the software testXpert II was used.

Results and analysis

The numerical results presented below have been obtained by simulating the same bending process with different materials for the deformable pad. All the other parameters of the model have been kept unchanged (punch stroke 20 mm, friction coefficient associated to the contact interfaces μ = 0.2). The analysis of the numerical results will be focused on investigating the relationship between the pad strength and the strain/stress state that develops in the blank during the bending process, the springback amount, and the evolution of the punch force.

Table 1 summarizes some of the most relevant output values of the finite element simulation. One may notice a direct relationship between the strength of the pad material (see the diagrams presented in fig. 4 and fig.5) and the maximum level of the equivalent stress developed in this component of the bending die. ESSIL 291-5 seems to be an exception from the rule formulated above (as compared

Table 1
OUTPUT DATA OF THE NUMERICAL SIMULATION FOR DIFFERENT MATERIALS OF THE DEFORMABLE PAD

Deformable pad			Blank		
Rubber	Reinforcement rate [%]	Maximum equivalent stress [MPa]	Maximum equivalent stress [MPa]	Maximum equivalent plastic strain [-]	Springback angle [°]
ESSIL 125	0	3.30	324.56	0.089	7°32’
ESSIL 125	5	6.48	317.82	0.090	6°22’
ESSIL 125-	10	7.76	322.90	0.091	6°41’
ESSIL 291	0	6.74	323.26	0.090	6°37’
ESSIL 291	5	9.73	322.66	0.092	6°25’
ESSIL 291	10	7.80	319.10	0.091	6°18’
ESSIL 291	15	13.52	323.46	0.094	5°57’
ESSIL 291	20	14.72	316.85	0.093	5°59’

with ESSIL 291-10, its strength is lower, but the corresponding equivalent stress is larger). Such a mechanical response is obviously unrealistic and must have been caused by the inaccurate fit of the experimental curve relating to the conventional stress and strain (fig. 5– case of ESSIL 291-5). Despite this fact, the predictions of the finite element program for ESSIL 291-5 are far from being totally anomalous, because the other ESSIL 291 materials have comparable values of the maximum equivalent stress and the numerical results referring to the blank are also in the same range.

The bottom position of the punch corresponds to the upper level of the blank loading. Such a position is presented in figure 5. The values of the equivalent stress listed in the fourth column of table 1 correspond to this configuration of the bending die (fig. 6 a). It is easily noticeable from table 1 that the strength of the deformable pad has a little influence on the blank loading. The same conclusion can be formulated when comparing the maximum values of the equivalent plastic strain listed in the fifth column of table 1 (fig. 6 b). This characteristic of the bending process is a consequence of the stiffness discrepancy between the metallic and rubber-like materials. Table 1 shows that the maximum equivalent stress is generally much lower in the pad than in the blank. Due to this fact, the pressure exerted by the deformable tool on the bottom surface of the metallic sheet is small. Under such circumstances, the strains and stresses developed in the blank are almost entirely defined by its mechanical properties and the punch profile. The similarity of the values listed in the fourth and the fifth columns of table 1 is now understandable.

Of course, the elastic strain accumulated in the blank should also feel only a slight influence from the deformable pad. That is why the springback angles listed in the fifth column of table 1 are different from each other only with small values. These values have been calculated using the coordinates of two nodes in the final configuration of the bending process (when the punch is retracted to the upper position of its stroke – fig. 7):

$$\beta = \arctan\frac{x_a - x_b}{y_a - y_b}. \qquad (1)$$

The symbols included in eq. (1) have the following significance:

β - unilateral springback angle,(x_a, y_a) and (x_b, y_b)- coordinates of the sample nodes *a* and *b*, respectively, both in the final configuration of the finite element analysis.

It is worth mentioning that the amount of elastic relaxation shown in table 1 is significantly larger than the one achievable in the case of a bending process with rigid tools and also larger than the usual tolerances of the bent parts. This is obtained only because the hardness of rubber is small while in cases where the hardness is higher elastic springback is much smaller [4]. The springback compensation is thus compulsory when using deformable pads. The simplest strategy that can be adopted in the industrial practice consists in overbending the blank around a punch with a modified profile (fig. 8). If performed by trial and error, the springback compensation can be a very expensive process. Computer simulation is a more efficient instrument for solving such a problem because it allows the designer to establish the optimum profile of the punch through iterations involving a reduced number of numerical tests, [8]. Figure 8 shows an exemplification of this procedure. The overbending correction of the punch (α=6°) has been established in three iterative steps. The final

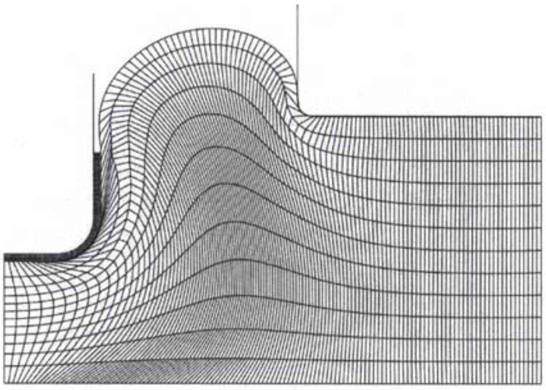
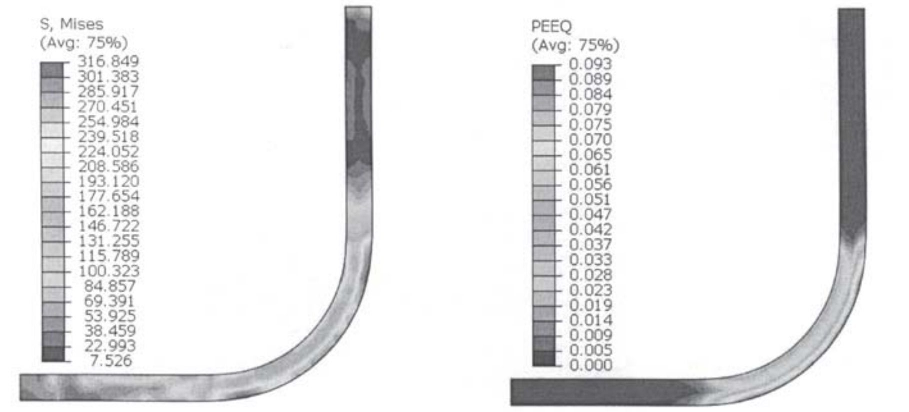


Fig. 5. Configuration of the finite-element model corresponding to the upper level of the blank loading (deformable pad made from ESSIL 291-20)



a. Distribution of the equivalent stress

b. Distribution of the equivalent plastic strain

Fig.6 Results from bending simulation for ESIL 291 -20% reinforcement

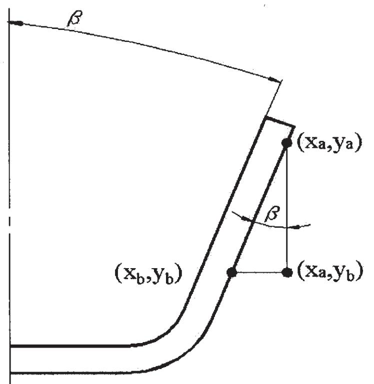
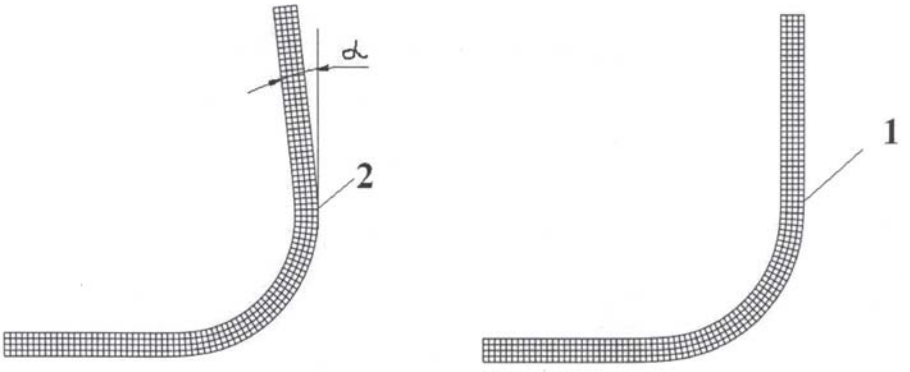


Fig. 7. Calculation of the unilateral springback angle



a- at the end of the bending

b- after punch removal

Fig. 8. Example of springback compensation through overbending (deformable pad made from ESSIL 291-20); 1 – original profile, 2 – modified profile, α – overbending correction)

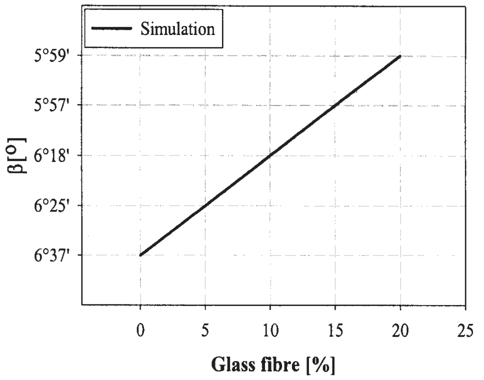


Fig.9. Evolution of springback angle due to the degree of reinforcement

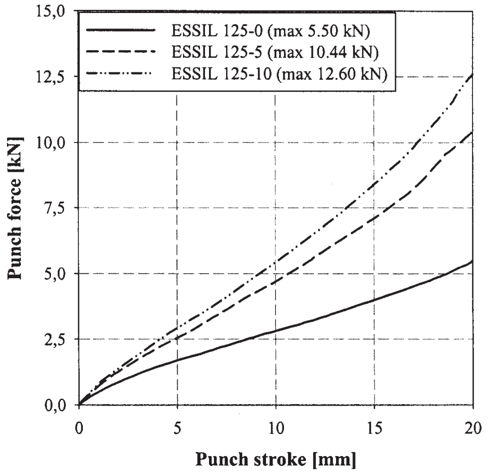


Fig. 11. Evolution of the force developed by the bending punch

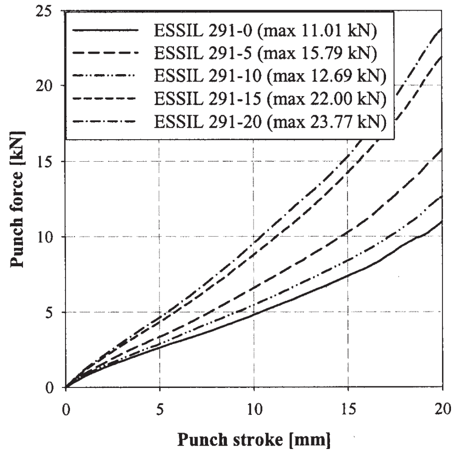


Fig. 10. Evolution of the force developed by the bending punch

solution presented in figure 8 corresponds to the deformable pad made from ESSIL 291-20 and guarantees a springback angle ($\beta=3'$).

Knowing the correct value of the spring back angle after load removal is important in order to make the correction for the punch geometry before bending. A diagram for the springback angle obtained with pads with a different degree of reinforcement was realised using data from the simulation program. It can be used as a prediction diagram considering its linear shape.

In contrast with the other parameters of the bending process, the evolution of the punch force is influenced by the strength of the deformable pad. This fact is visible on the diagrams shown in figures 10 and 11.

One may notice a direct relationship between the characteristic curves of the pad material and the maximum level of the punch force. Again, ESSIL 291-5 does not follow the general trend but, as mentioned above, its anomalous behaviour is determined by the inaccurate fit of the experimental curve relating the conventional stress and strain. Even if the deformable pad exerts a small pressure on the bottom surface of the blank, its counteraction becomes significant when the distributed load is multiplied by a large contact area. The aspect of the evolution curves shown in figure 10 is thus explainable.

Conclusions

Bending with elastic pads is a technology that has some advantages compared with the classical one and that makes it very useful to be studied. The strains and stresses developed in the blank are almost entirely defined by its mechanical properties and by the punch profile. The strength of the deformable pad has a little influence on the blank loading. There is a direct relationship between the characteristic curves of the pad material and the maximum level of the punch force.

The maximum equivalent stress is generally much lower in the pad than in the blank. Due to this fact, the pressure exerted by the deformable tool on the bottom surface of the metallic sheet is small.

Knowing the correct value of the spring back angle after load removal is important in order to make the correction for the punch geometry before bending. Computer simulation is an efficient instrument for solving the problem of calculating the springback angle because it allows the designer to establish the optimum profile of the punch through iterations involving a reduced number of numerical tests. In this way, in the industrial practice, it is only necessary to overbend the blank around a punch with a modified profile.

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