Experimental design on bimaterial forming

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Abstract:

The main idea of this paper is to improve our knowledge on metal forming when the initial sheet is a bimaterial that is to say with two materials in the thickness. First of all, the behaviour of both materials (aluminium and steel) is studied separately to know their elastoplastic behaviour; thus, the behaviour of the bimaterial can be studied. An experimental design is done on an industrial press using a punch variable in width and depth. Besides, this forming operation has been simulated with a finite element code, with the specific punch, on the bimaterial. The aim of this experimental design is to understand the part played by each material and to better understand the final geometry of the part and the appearance of cracks or not. This study is both experimental and numerical and brings highlighting on the plastic behaviour of a bimaterial that means showing heterogeneities at a macroscopic scale.

Keywords: forming, bimaterial, experimental design

1 Introduction

In order to improve the production of certain industrial parts done in bimaterials, it is, for example, possible to use the production of well by forming instead of milling. This technology enables to increase the productivity but has important impacts on the quality of parts and needs to acquire an accurate knowledge on heterogeneous metal forming by plastic deformation.

Different experimental [1,2], numerical [3,4,5] and theoretical [6,7] studies were carried out on bimaterials. A. Najafi et al. [2] have proposed a new structural design which allows the tuning of the thermomechanical response of a bimaterial microcantilever. The results show the flexibility and the potential of this design. The deformation behaviour of bimaterial specimens has been investigated by G. shatil et al. [3]. Fracture toughness and fatigue crack growth tests and numerical simulations on specimens were carried out to study the behaviour of a crack lying perpendicular to the interface in a ductile/brittle bimaterial. The authors found that the elastic crack opening displacement is about 10 times larger than that of the homogeneous specimen. This is partly attributed to the decrease in stiffness of the bimaterial in comparison with aluminium. R. Hadayati et al. [7] have studied the mechanical properties of additively manufactured porous biomaterials based on a relatively new type of repeating unit cell, namely truncated cuboctahedron. The result show that as for the yield stress, the experimental values were between the two lines corresponding to the yield stresses predicted for the two most critical points of the porous structures, indicting good agreement between experimental, analytical and computational values of yield stress.

This aim of this work is to study a bimaterial during plastic forming. This step of forming is studied both in an experimental way on an industrial press and in a numerical way thanks to an experimental design. What is original in this work, is to consider this work as the first step towards a better understanding of what happens inside heterogeneous materials such as dual phase steels for example. Indeed, dual phase steels [8] are nowadays particularly popular materials for the production of parts obtained with deep-drawing process. These materials have a particularly heterogeneous structure, that is to say that they can be considered as composite structures. It is this melting of different properties, such as ductility and hardness, that confers remarkable mechanical properties to this material. It will be the same idea with the strip of steel and AlSn used in this study. The question raised here is to know how a heterogeneous structure has an impact on the overall plastic behaviour of materials, particularly during forming [9], but also at the onset of localization or springback [10]. A study of the effect of localization through the appearance of cracks will be lead here looking the impact on plastic behaviour [11-12]. The idea is afterwards to develop models in which the material heterogeneities are directly considered, so that the results generated by the numerical simulations will be more accurate; it has been checked on springback study [13].

The first paragraph of this paper presents the materials. Then, the second paragraph is dedicated to the experimental study of the forming operation. Afterwards, the numerical simulation of the forming operation is exposed. Finally, conclusions and perspectives are given.

2 Studied materials

The studied material is a strip of bimaterial with a width of 17 mm and a total thickness of 2.6 mm with 0.6 mm of AlSn and 2 mm of steel. The presence of AlSn aims to reduce the friction on the final part and steel gives its rigidity and its low cost. Mechanical and physical characterizations of each material have been done: chemical composition, hardness, micrographies and tensile tests. The tensile tests have been achieved on a INSTRON device (5569) with a load cell of 50 kN with an imposed speed of 7 mm/min. Strains are measured with extensometer and also by digital image analysis [14] (it was useless seeing the weak hardening of both materials; DIC does not give more information seeing the necking is weak). Samples with a single material have been cut without the other material in the central zone. The tensile curves have been then obtained for steel, AlSn and bimaterial (Figure 1).

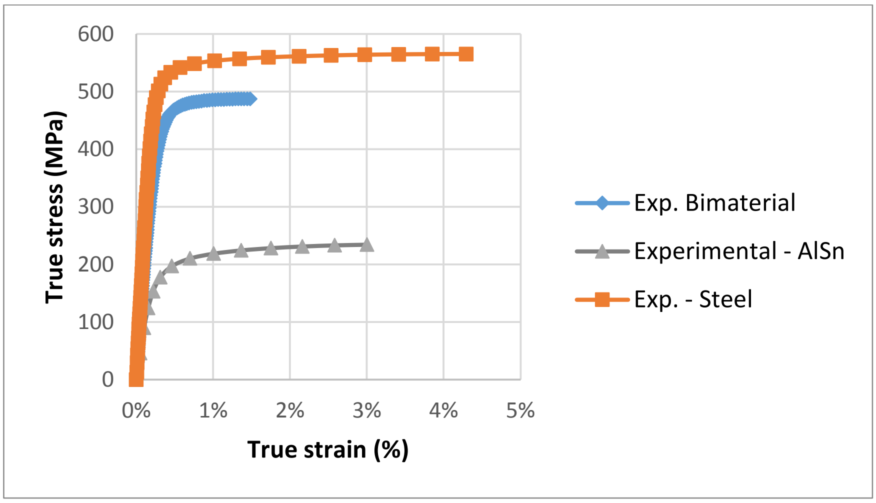


Figure 1: Tensile on steel, AlSn and bimaterial

As it was impossible to realize the tensile tests in other directions seeing the dimensions of the strip (17 mm in width), the behaviour of the materials will be supposed to be isotropic.

2 Experimental design of forming

To understand the behaviour of the bimaterial during forming, an experimental design (composite centred type with at least 9 tests) has been reached (Table 1) on an experimental press. Only two parameters are variable: the width of the punch (from 1.8 mm to 2.8 mm with a possible variation of 2 mm) and its depth (from 0.8 mm to 1.8 mm with a possible variation of 2 mm); all the other parameters of the experimental test will stay identical. In this study, only 2 tests will be presented: L18P16 and L22P06.

Test	Width	Depth	Remark
L18P12	1.8	1.2	
L18P16	**1.8**	**1.6**	**Cracks**
L22P12_1	2.2	1.2	
L20P08	2	0.8	
L20P18	2	1.8	
L22P06	**2.2**	**0.6**	**No cracks**
L22P08	2.2	0.8	
L22P12_2	2.2	1.2	
L22P20	2.2	2	
L26P08	2.6	0.8	
L26P18	2.6	1.8	
L26P08	2.8	0.8	
L28P12	2.8	1.2	
L28P16	2.8	1.6	
L22P12_3	2.2	1.2	

Table 1: Experimental design for experimental press

The experimental tool is given in Figure 2-a and 3 samples have been obtained for a width of 1.8 mm and a depth of 1.6 mm visible on Figure 2-b.

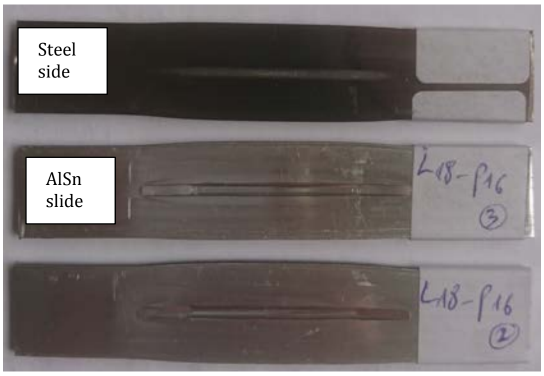


Figure 2: a- Punch for the forming test b- Samples for test L18P16

The main issue, during the metal forming, is the presence of cracks on the sample on the steel side (visible on Figure 2–b).

The displacement of the material could be highlighted by means of tomographic images (Figure 3). It can be seen that AlSn, initially on the upper surface of the sample, completely disappeared during the formation of the well. It is also interesting to see that, although the punch has a rectangular cross-section, the deformed material is V-shaped. A crack is also visible on the right tomography in the lower part of the work piece, i.e. on the steel side.

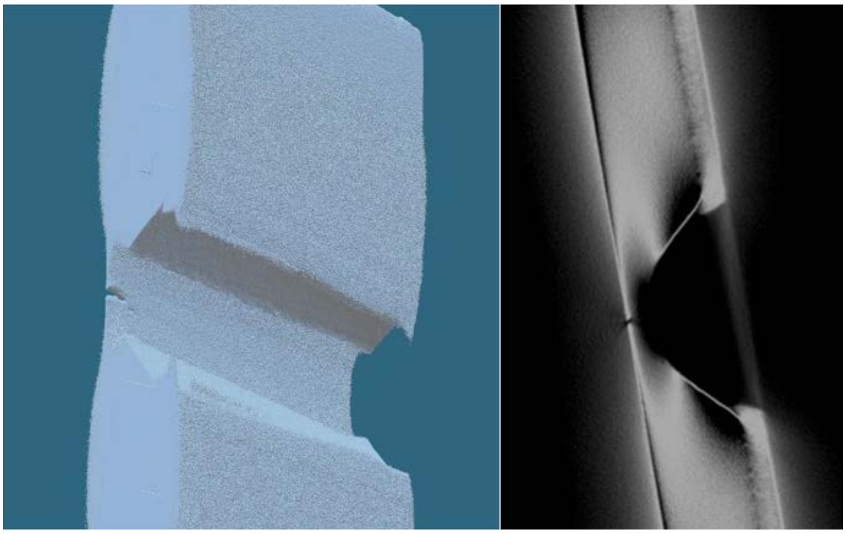


Figure 3: Tomographic images on sample L18P16

3 Numerical simulation of forming

The critical forming operation was simulated with Abaqus / Explicit finite element code (Figure 4) using a double precision calculation mode. The punch is described by discrete rigid surface, the anvil by analytical rigid surface and the strip by deformable surface. The metal sheet has a width of 17 mm, a thickness of 2.6 mm with 0.6 mm of AlSn and 2 mm of steel, as the material used experimentally. The sample is finely meshed on ¼ of a piece (conditions of symmetry imposed) with elements of C3D8R type with 21 elements in the thickness, 40 in the width and 120 in the length.

The material is assumed to be homogeneous and isotropic. In the elastic range, the material behaviour is modelled by Young's modulus and Poisson's ratio. The reference curve between the yield stress and ultimate tensile stress can be described by an elastoplastic model with a Von Mises plasticity criterion and isotropic hardening according to Hollomon's law. This later which is a power law relating the true plastic strain ε_p^n to the true stress σ is given by:

$$\sigma = K\varepsilon_p^n \tag{1}$$

where K and n have been identified by fitting the experimental curves (Figure 1).
All the elastoplastic parameters of both materials introduced in Abaqus are given in Table 2.

Material	Young's modulus (MPa)	Yield stress (MPa)	Density (kg/m^3)	Poisson's ratio	K (MPa)	n
Steel	216 507	451	8 010	0.3	589.6	0.0122
AlSn	69 824	153	2 700	0.3	269.5	0.0388

Table 2: Elastoplastic parameters of the 2 studied materials

About boundary conditions:

- the anvil is fixed
- the displacement of the punch depends on its depth
- the friction coefficients are: AlSn - punch 0.01 and steel - anvil 0.1

A first step (time 0 to 2 s) corresponds to the descent of the punch and the second step (time 2 s to 3 s) corresponds to its ascent. An overview of the simulation is given Figure 4.

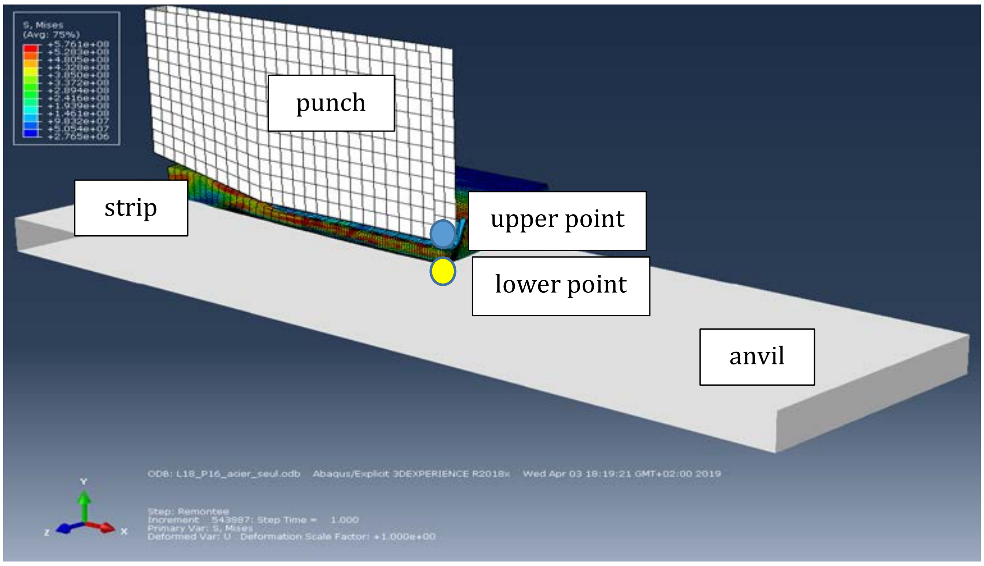
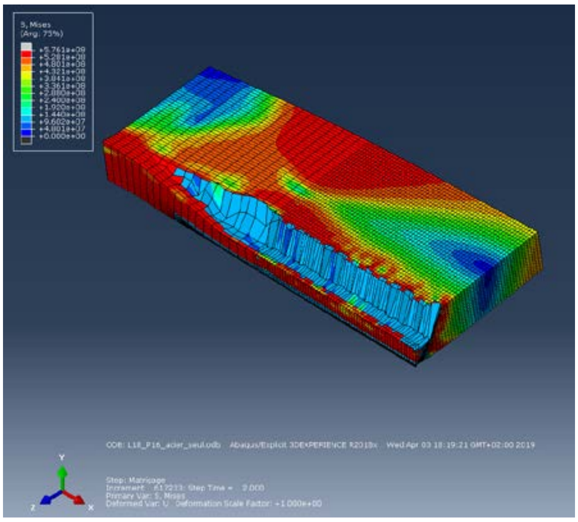


Figure 4: Numerical simulation of forming on sample L18P16

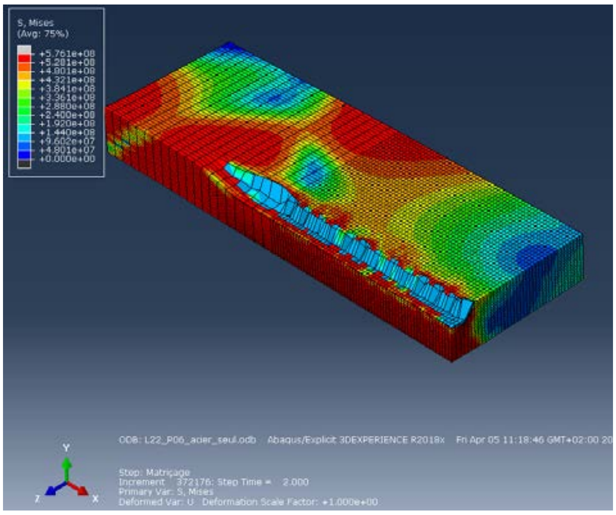
Two cases were more specifically studied in this paper: L18P16 and L22P06 respectively showing and not showing cracking on the steel side.
Three configurations were also tested: the bimaterial in the same proportions as the experimental one, steel alone with a thickness of 2.6 mm and AlSn alone with a thickness of 2.6 mm to see the influence of the presence of the bimaterial compared to a single material. It is possible to observe the equivalent von Mises stress in the 6 configurations at 2 times of the numerical simulation: at the end of the descent of the punch (t = 2s) and at the end of the ascent of the punch (t = 3s) on Figure 5 to Figure 7.

L18P16 – Steel alone

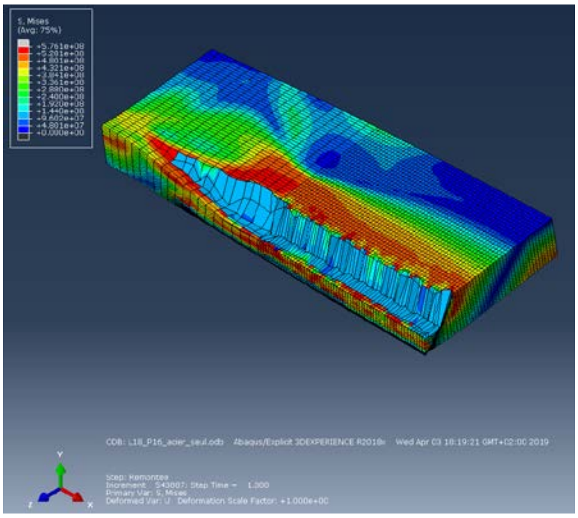


t = 2s

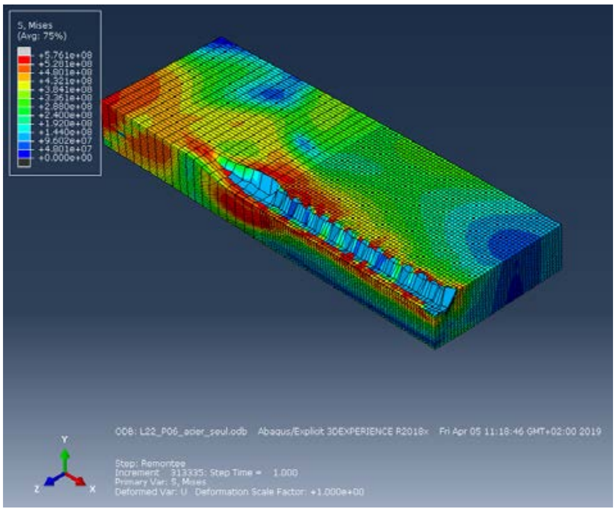
L22P06 – Steel alone



t = 2s



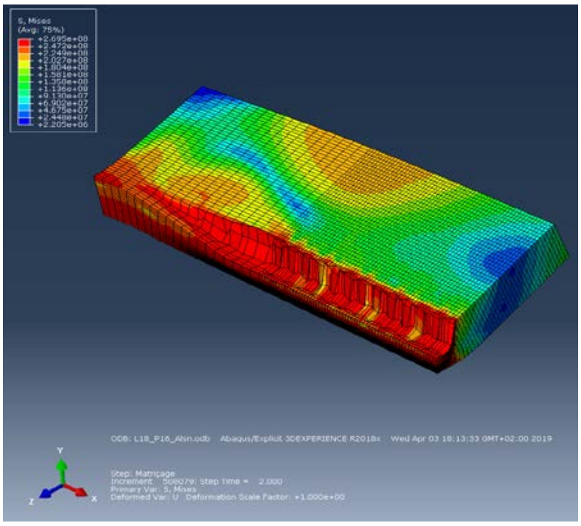
t = 3s



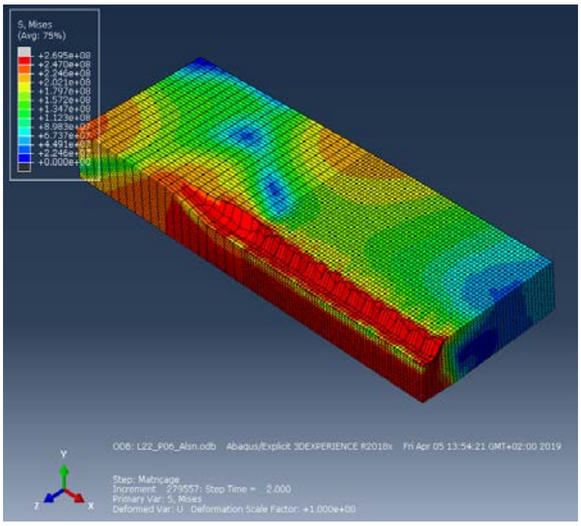
t = 3s

Figure 5: Von Mises stresses on sample with steel alone

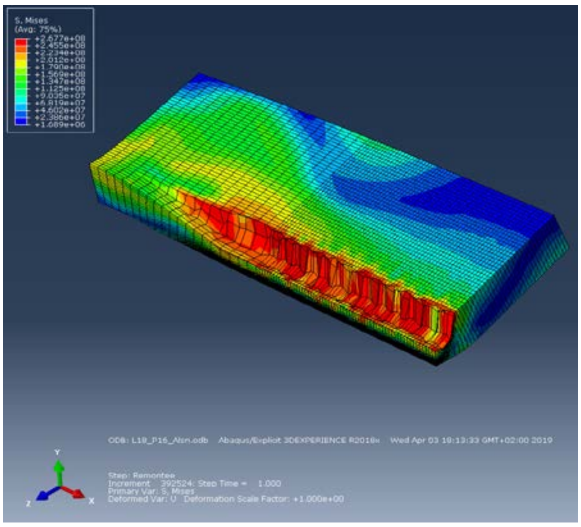
L18P16 – AlSn alone **L22P06 – AlSn alone**



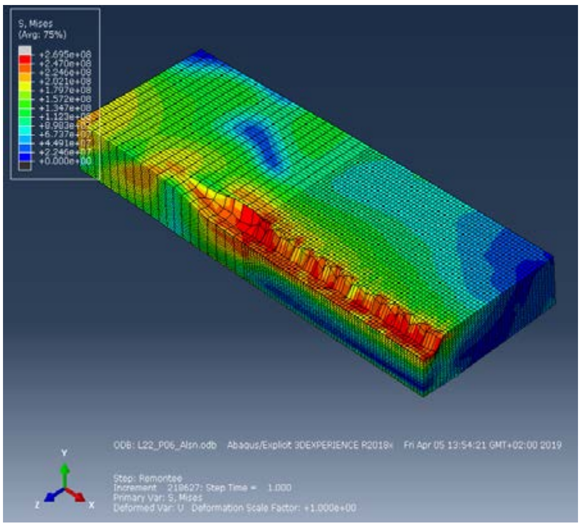
t = 2s



t = 2s



t = 3s



t = 3s

Figure 6: Von Mises stresses on sample with AlSn alone

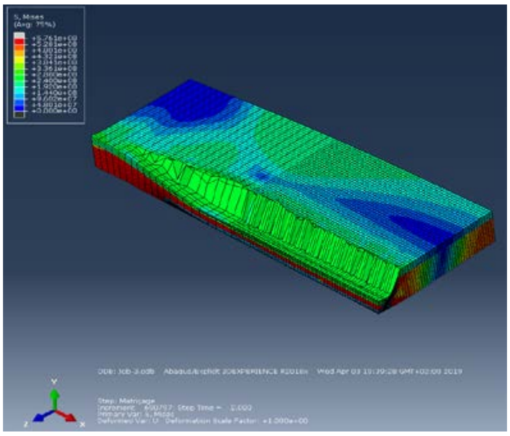
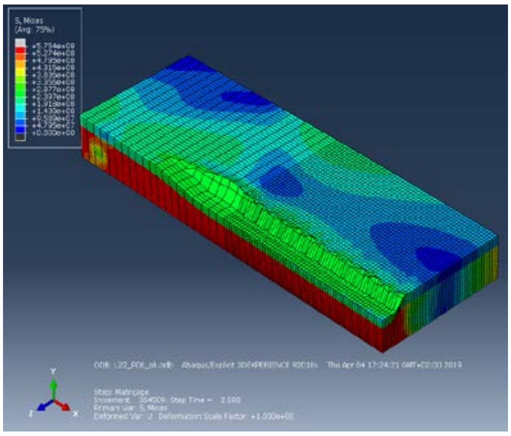
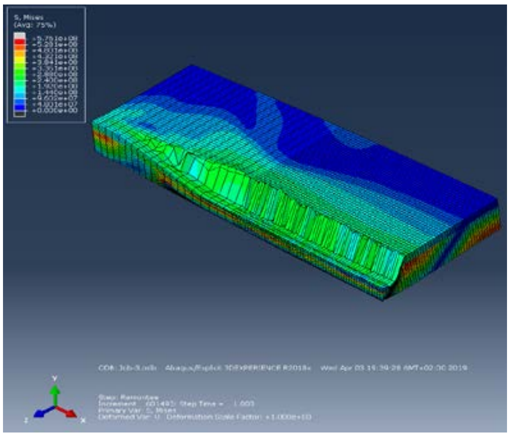
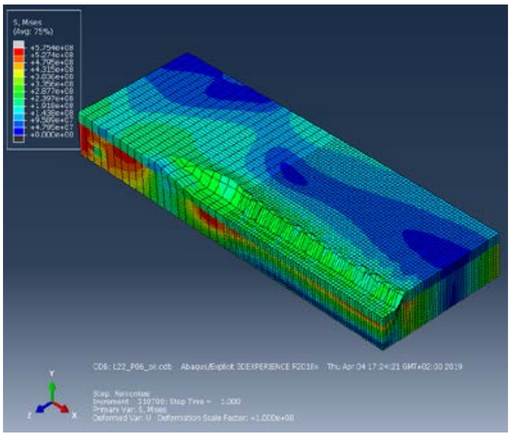
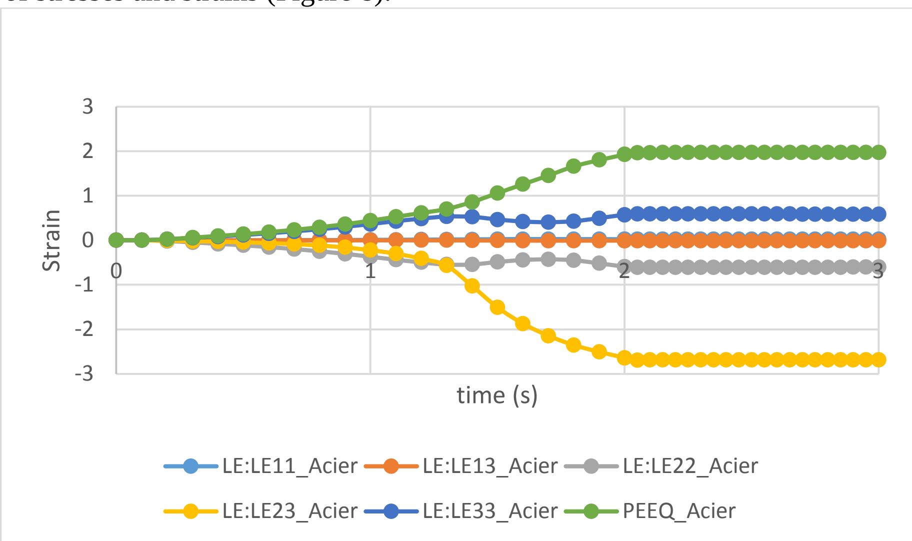
L18P16 – bimaterial	**L22P06 – bimaterial**
	
t = 2s	t = 2s
	
t = 3s	t = 3s

Figure 7: Von Mises stresses on sample with bimaterial

It can be seen that the stress state is higher during the simulation of the deepest well (L18P16). It can also be noted that the maximum strain takes place on the face below of the sample.

For the simulation L18P16 with bimaterial, it is interesting to look at which solicitations are present on the upper and lower central points of the sample and to see the temporal evolution of each of the components of stresses and strains (Figure 8).



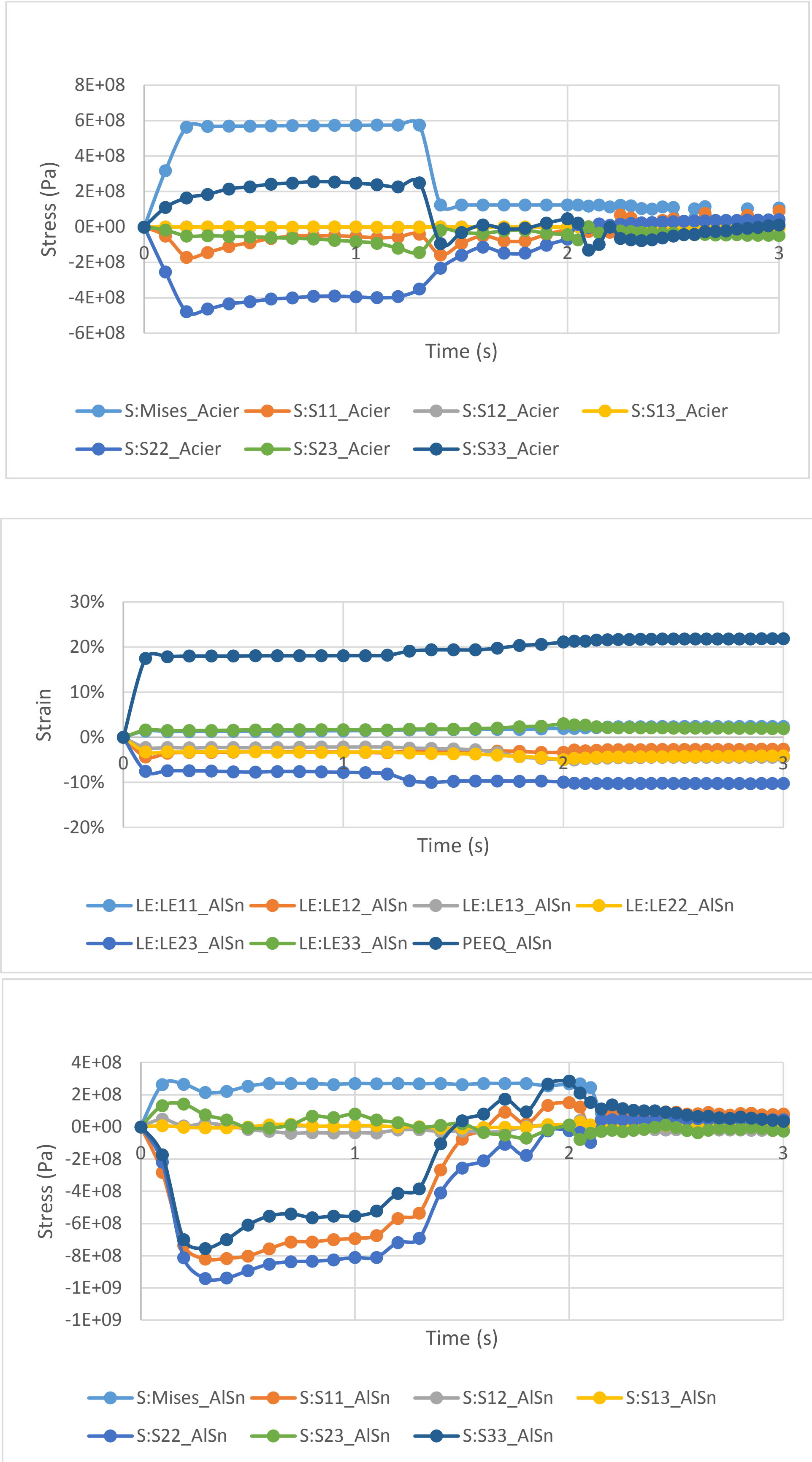


Figure 8: Temporal evolution of stresses and strains at the high and low center points of the sample during forming of bimaterial.

Concerning the prediction of the appearance of cracks, during L18P16 simulation, it is linked to the discharge of certain elements on the steel face of the sample. In Figure 9, if one plots the evolution of the equivalent von Mises stress as a function of the equivalent plastic strain, we can see that before the end of shaping by the punch (about t = 1.5s) , elements are discharged (stress drops) while others remain on the reference curve. This means that there has been localization somewhere [15-16]. We are currently working on finding a criterion on the counting of these discharged elements from the lower face to predict the cracking or not of the part during the forming.

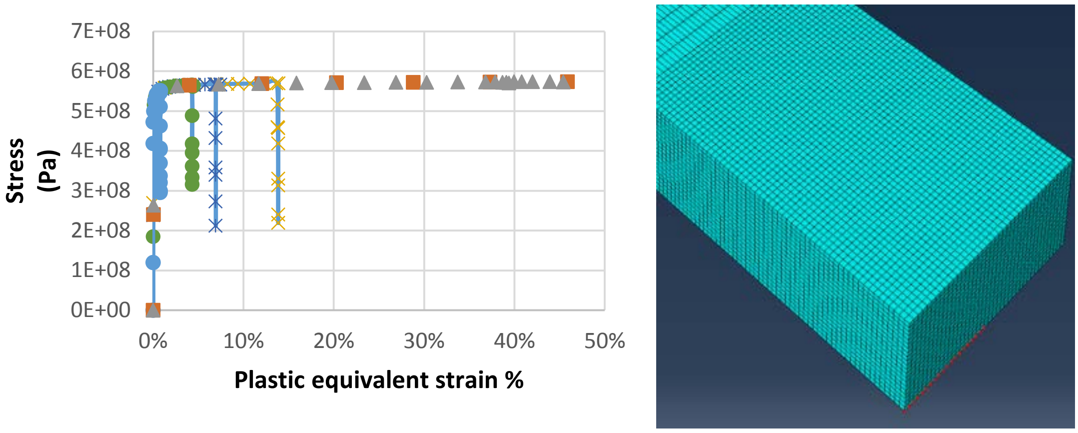


Figure 9: Evolution of the equivalent von Mises stress as a function of the equivalent plastic strain for different points of the line on the lower surface.

4 Conclusions

Through this study, partially presented in this article, an important work has been done by an experimental design of forming a bimaterial both with an experimental part and a numerical one. The main objective was to understand what happens when forming a bimaterial that we can consider as a material with a high heterogeneity. We have found again the phenomenon of cracking by the presence of elements unloaded on the steel side of the sheet and the development of the numerical simulation seems to reproduce the reality, knowing that we have taken every precaution to characterize the two materials in presence. Further studies are undertaken to understand the role of each material by varying their proposition and their nature to see what facilitates the forming. This study has to be seen as a first step towards the study of heterogeneous materials if one wants to change the observation scale, and to study dual phase steels for example.

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