Metal inclusion influence on mechanical behaviour of plates made of araldite

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Abstract. Due to the need for creating new, more efficient, materials for use in structures manufacturing, a high interest issue for researchers and engineers is to analyze the plastic or composite material defects and their influence over the mechanical behavior of the structures. Presented in this paper are the results of experimental analysis and its validation, made by finite element numerical analysis. The first part of the analysis process consisted in obtaining the reference values from plastic plates containing no metallic inclusions, which were analyzes both experimentally and numerically, by subjecting them to a flexural load. A numerical validation of the experimental model was obtained. Next, same kind of numerical and experimental analyses were performed, but this time plastic plates containing metallic inclusions were subjected to the same loads as before. In doing so, the study revealed the local and global influences of inclusions over the mechanical behavior of plastic plates.

Keywords. plastic plates; metalic inclusions; strain;

1. Introduction

High mechanical performances of state-of-the-art composite materials due to their structure and mechanical properties have greatly improved the manufacturing technologies from top industries, producing important changes in engineering design. Unlike the traditional design, in which the main dimensions of a structure are calculated taking into account the loads and mechanical characteristics of the material, the design philosophy for composite materials is based on structural concepts. Starting from the functional architecture of the structure and loading, the design calculations aim to the macrostructural organization of the material, to ensure a high degree of safety with minimum material consumption [1].

Research and development of multi-layered metal inclusions in plastic materials, represents a future trend in the use of nonconventional honeycomb structures. In these structures, different damage processes exist, such as matrix cracking, delamination, and fiber breakage. These affect the structural performance of the components by reducing their stiffness and can lead to premature failure. Therefore, detecting this damage is a crucial issue for safety reasons. A large amount of work has been done on this subject. Among the studied damage indicators, one can find some local measurements reflecting a global behavior like deflections. They can be a marker of the onset of delamination and/or cracks during a mechanical stress [2]. Delaminations and cracks will be visible in force/displacement

curves as sudden drops. Another local indicator is the modal frequencies. As Eigen frequencies are affected by the global stiffness of the component, a slight change of their values means that the structure has been altered. Even though these local indicators are easily accessible as they come from a single point, it is not possible to localize a damage. If ones want to localize the damage, these local data are not enough but if one creates an array of sensors, it will be possible, using piezoelectric sensors for example. These methods are based on the temporal analysis of a signal and triangulation to determine the location of the damage. Another method consists in looking at the mode shapes, either displacements or slopes. If one extends this idea of multi-point measurements as done with a vibrometer for instance, to extract the modes, we will arrive at full-field measurements [3]. A full-field technique provides data over an area with a high density of information. Because of this characteristic, these techniques are well suited for damage detection. They can be classified in two categories based on the type of their measured quantities: non-destructive testing (NDT), giving only location information and kinematic measurements, giving mechanically related information.

1.1. NDT

The most widespread NDT techniques comprise visual inspection, C-scan, CT-scan, and thermography. They will be reviewed in this section. Visual inspection is very well suited for defects where visible surfaces are affected by the damage but it does not provide information about the damage state through the thickness. It is fast, inexpensive and gives an appreciation of damage severity but it cannot detect internal damage. Another drawback is that it is operator dependent.

Ultrasounds are a group of techniques based on the fact that ultrasounds are reflected at interfaces between materials of different properties. An ultrasonic wave is induced in the material, and the reflected waves are recorded along time. If the available data are the amplitude of the waves as a function of time, the A-scan representation can be used, amplitude versus time. If the location in 1D of the probe and the amplitudes are available, the B-scan representation, amplitude versus location, can be used and the 2D extension of a B-scan is C-scan. It is not too expensive and is widely used as a base for damage detection. It allows a localization of the damage in 2D but does not give any indication along the third dimension. Another drawback is that it is difficult to perform in situ on a mounted component.

The CT scan technique allows reconstructing a volume from several X-ray pictures of the component rotated by a controlled angle. It is the finest method; it allows navigating through the whole volume looking for signs of damage. The first drawback is the time required to acquire the data, as the final resolution depends on the number of X-ray pictures.

Thermography relies on the fact that a delamination will introduce a delay in heat diffusion as thin air layers between the two delaminated plies will act as thermal insulators. The thermal gradient can be introduced using a hair drier for instance, and the cooling down can be observed at with a thermal camera. This technique is well suited if one wants to just locate damage regardless of severity. However, it is limited to thin components or shallow delaminations on thicker components.

1.2. Kinematic measurements

All These methods give access to maps of mechanical quantities such as displacements, slopes or strains. This group of methods includes shearography, holography, image correlation, thermoelasticity, the grid method and deflectometry. This section briefly reviews these methods, starting with shearography. It is a differential interferometry technique that is sensitive to local slopes. It is very sensitive as it is based on interferometry and is usually associated with thermal loading. An advantage for this technique is that even though it is based on interferometry, it is reasonably insensitive to vibrations as opposed to holography. The drawback is the fact that it gives only qualitative information.

Holography or Electronic/Digital Speckle Pattern Interferometry generally allows to obtain deflection fields and it is also based on an interferometry phenomenon. It is very sensitive and can be associated with thermal loading. It can be also used in dynamic testing to extract mode shapes for

instance. It is also possible to use it with a vacuum loading. The downside of this technique is his strong sensitivity to vibrations.

Digital Image Correlation (DIC) is more and more widely used because of its low cost and ease of use. It is based on tracking the deformations of sets of random patterns. As it provides displacements, it is more suited for in-plane applications as only one differentiation is required to obtain the strains. For the out-of-plane configurations, strains are proportional to curvatures which are double derivatives of out-of-plane displacements within the thin plate theory (Love–Kirchhoff). These two differentiations decrease the signal to noise ratio leading to the necessity to use some smoothing. Therefore, DIC will present a poor resolution to spatial resolution compromise. It has been used to detect delaminations or track cracks as in for in-plane loading configuration. As the method is not very sensitive, higher deformations are required than for the shearography technique for example.

The grid method looks at the movements of the grid pitches and it has been used to assess the damage development. It requires the use of a micrometric grid bonded onto the surface and provides 2D in-plane displacement fields if a crosshatch grid is used. The major problem with this method is to have a grid with a constant pitch in both directions.

To measure out-of-plane information, the grid method can be used in specular reflection, which is known as deflectometry. The measured quantities are not displacements but surface slopes and with a differentiation the surface curvatures are obtained. They can then be converted into strains using a thin plate assumption. The complete procedure is detailed later in this paper. This technique is not onerous but is limited to plane surfaces and requires a reflective coating if the sample does not exhibit sufficient (mirror-like) specular reflection. It has already been used for damage characterization using the virtual fields methods with samples containing an area with reduced stiffnesses. It is a very sensitive method and the sensitivity is tunable independently from its spatial resolution. It must be noted that the techniques mentioned previously can be organized differently depending on their use, in situ damage detection (visual inspection, ultrasounds, thermography and shearography) and basic understanding of damage mechanisms and validation of design procedures (Holography, DIC, thermoelasticity and grid method) [4-7].

As the deflectometry technique has never been used to experimentally determinate the metal inclusion influence on mechanical behavior of plates made of plastic, this paper will investigate the use of deflectometry to obtain a surface ''signature'' linked directly to the presence of one or several strains that appear in the specimens. The paper describes the experimental procedure: material, layup and sample type, then the measurement technique [7-10].

2. Experimental conditions

Samples made of plastic (Araldite) resin were obtained by cutting a 2.5 mm thick plate, which was casted with several metal inclusions embedded inside, see Fig. 1.
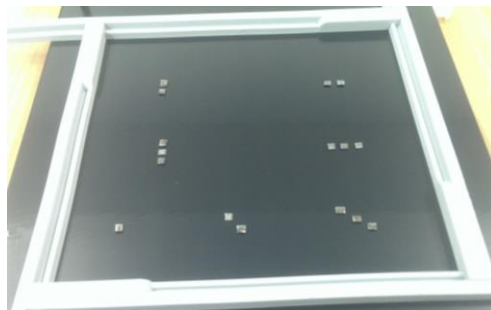

Fig. 1. Layout of inclusions on the araldite plate

The plate was obtained by mixing a room-temperature-curing resin and hardener. The material has a high strain optical constant (approximately 0.10). It is primarily used to coat metals and many other high-modulus materials exhibiting elongations of less than 5%. In order to highlight more the

influence of the metal inclusions, multiple ones were positioned in two configurations: one linear and one at a 45 degrees angle, thus obtaining six samples:

- The reference one, that has no metal inclusion
- One samples that has one inclusion, positioned in the center
- Two samples that have two, and respectively three inclusions positioned linear
- Two samples that have two, and respectively three inclusions positioned at a 45 degrees angle

The test samples consists of a 60x25x2.5 mm Araldite plate overlapped a 300x25x6 mm aluminum rod. Each specimen was bonded to the aluminum rod using special reflective glue, see Fig. 2.

Fig. 2. Test sample.

The test sample material properties are summarised in Table 1.

Table 1. Mechanical properties of the materials.

Material	Elasticity Modulus (*MPa*)	Poisson's ratio
Araldite	2900	0.36
Steel inclusions	210000	0.29
Aluminum rod	69000	0.33

For each test a number of minimum tree points were measured. The specimens were stressed by controlling the displacement of the bending rod using six 1.25 mm steps up to 7.5 mm displacement. The results presented in this paper were obtained for the 7.5 mm displacement. One end of the bending 300 mm rod was clamped and the other was displaced.

Fig. 3. . Flexural device.

The flexural device, shown in Figure 3, consists basically of a rigid cast frame for mounting and deflecting a cantilever beam. The beam is loaded at its free end by a precision micrometer, permitting accurate measurement of the deflection. When a beam, to which a test sample has been bonded, is mounted in the calibrator and then deflected by a predetermined amount, a known state of strain is imposed upon the coating. Measurement of the resultant birefringence in the coating provides the necessary information for relating fringe order to principal strain difference.

The testing was carried out using the Vishay Micro-Measurements Photo Stress technology, see Fig. 4. White light generated by the light source propagates through a polarizer and quarter wave plate. The circularly polarized light then travels through the sample material that has been bonded to the aluminium rod with the special reflective adhesive.

Fig. 4. Experimental setup.

The light then travels back through an additional analyser and quarter wave plate. The image is then captured with a digital video camera, and transferred to a computer equipped with specific software which enables the user to store and process all the acquired data, see Fig. 4.
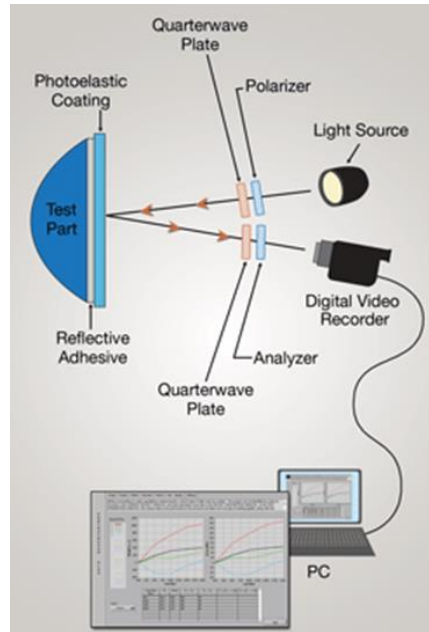

Fig. 5. System configuration.

Using an electronic compensator and the computer software it was achieved the measurement and calculation of stress/strain values. At the point of measurement, an initial no load (Ro) reading is made with the compensator, see Fig. 6. A second reading (R load) is then made after loading the part. After this, null balance readings are made and the numerical information is then electronically transferred to a computer.

Fig. 6. (a) Ro; (b) R load.

The principle strain directions are measured with reference to an established line, axis, or plane. Therefore, the initial step for the determination of the direction of principle strains (or stresses) was to select convenient reference.

When the plane polarized beam of light transverses the sample subjected to stress, it splits into waves propagating at different speeds along the directions of principle strains. After emerging from the plastic, these two waves have been out of phase with one another and have not recombined into a single vibration parallel to the one entering the sample. However, at points where the direction of the principle stresses are parallel to the axes of polarizing filter, the beam will be unaffected and the emerging vibration will be parallel to the entering one. An analysing filter with its axis perpendicular to the polarizing filter will reproduce extinction of the vibration at these points.

In order to carry out the validation, the corresponding finite element models were created using the ANSYS pre-processor software, for all the sample types. All the conditions of the analyses were defined by complying with the real model. One end of the aluminium rod was defined as clamped and to the other end a 7.5 mm displacement was imposed. The mesh for these analyses was made using solid elements. The mesh on the overlapped araldite plate was refined in order to obtain higher accuracy, see Fig 7.
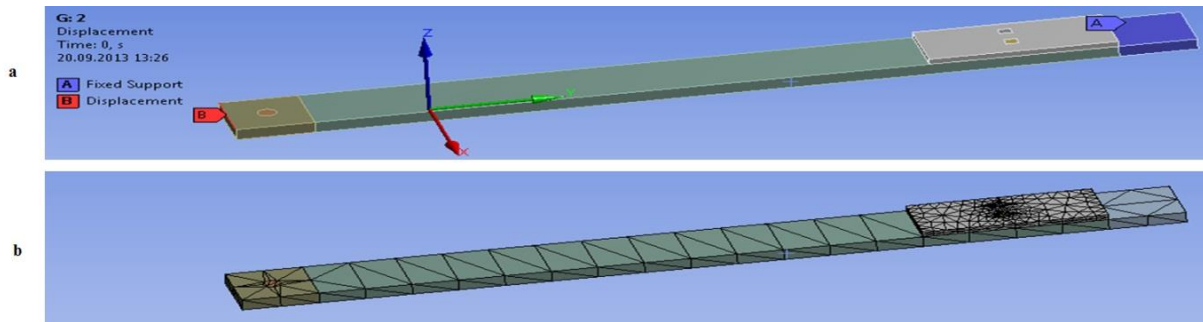

Fig. 7. (a) Boundary conditions; (b) Solid element mesh.

3. Results and discussion

In the following representations of the equivalent strain maps, the upper edge is the clamped zone, and the load is applied at the middle of the lower edge as presented in Fig. 7(a). For ease of comparison, the two models are placed side by side for each type of sample. It can be observed that the reference sample has a uniform distribution of strain in both cases, see Fig. 8
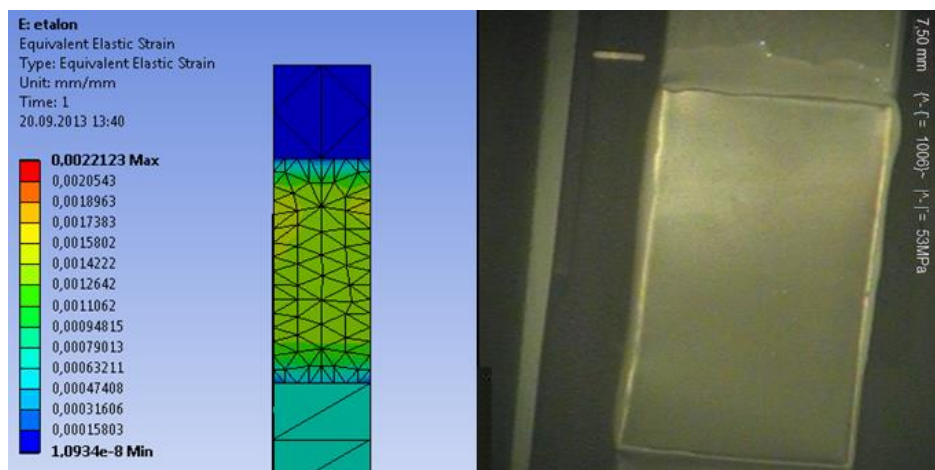

Fig. 8. Reference Sample.

So we have the numerical model in the left side and the experimental one in the right side. Second sample tested after validation was the one with one metallic inclusion positioned right in the center. It can be observed the concentrator effect that appears at the corners of the inclusion. Also on this sample we can see the calibration points used in the adjustment process for reading the results, see Fig 9.
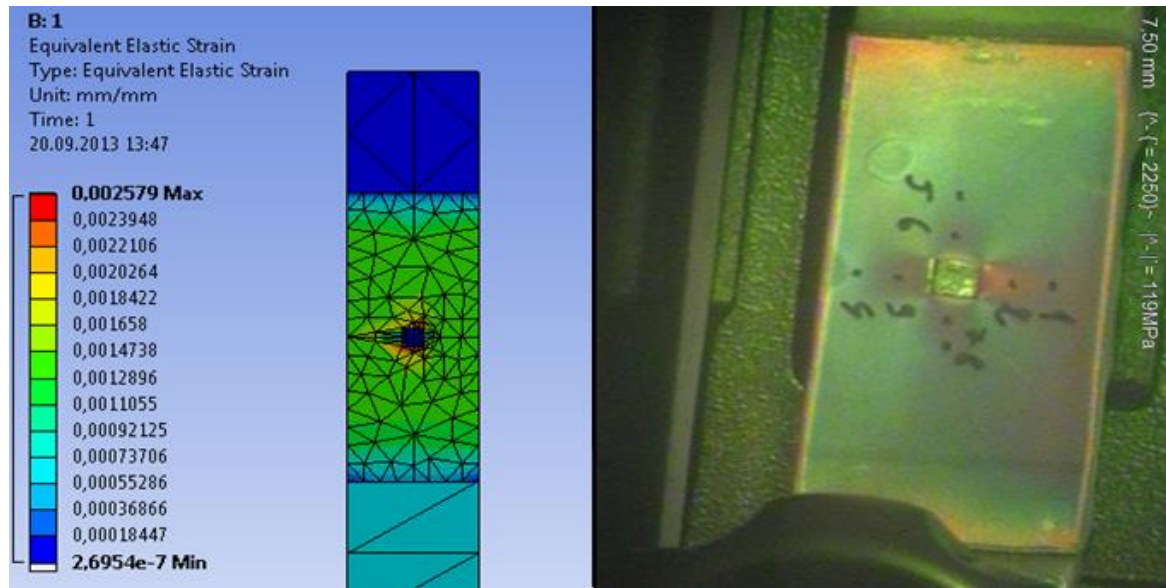

Fig. 9. One inclusion sample.

With both images of results presenting the strains that appear in the sample, it can be observed in both cases a very good correlation between the finite element analysis and the experimental measurements see Fig. 10.
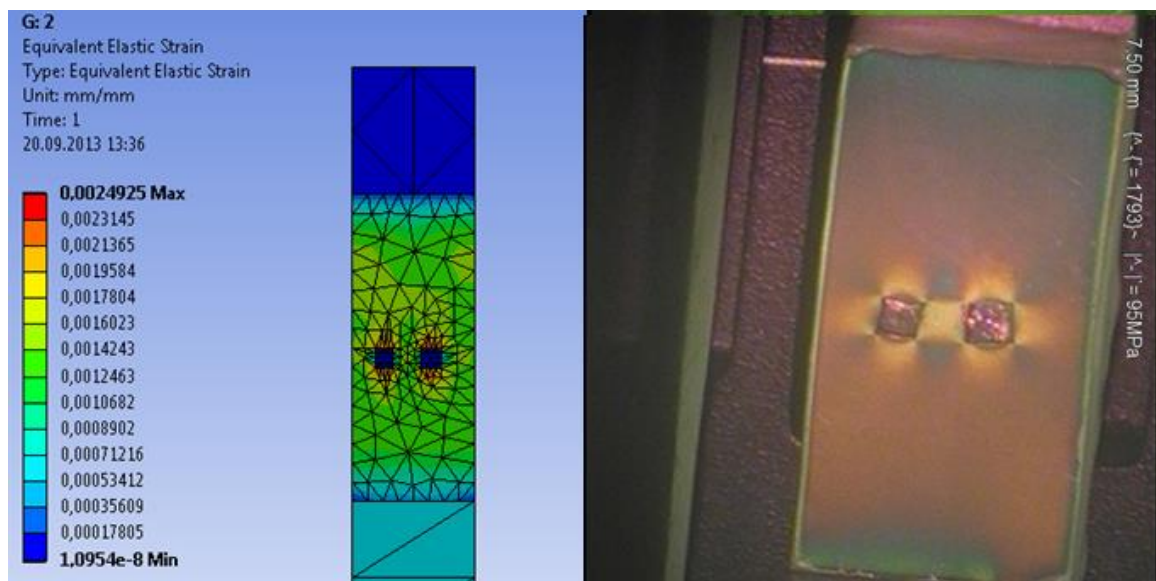
Fig. 10. Two inclusions sample.

The results shown in Fig 11, Fig.12 and Fig. 13 concludes this study and gives us a detailed picture on the influence of metal inclusions on mechanical behavior of plates made of plastic.
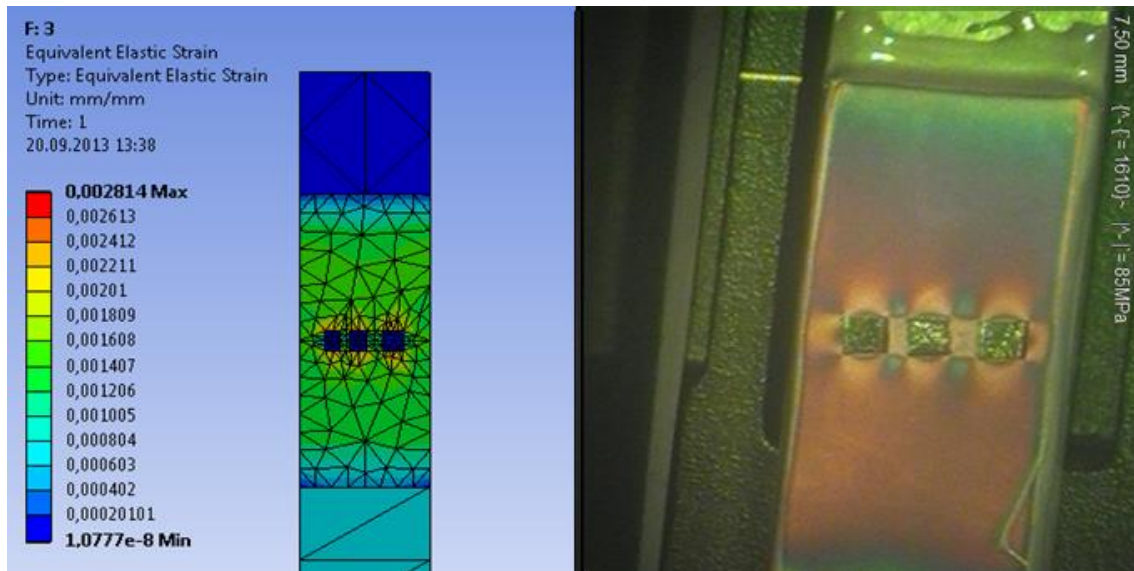

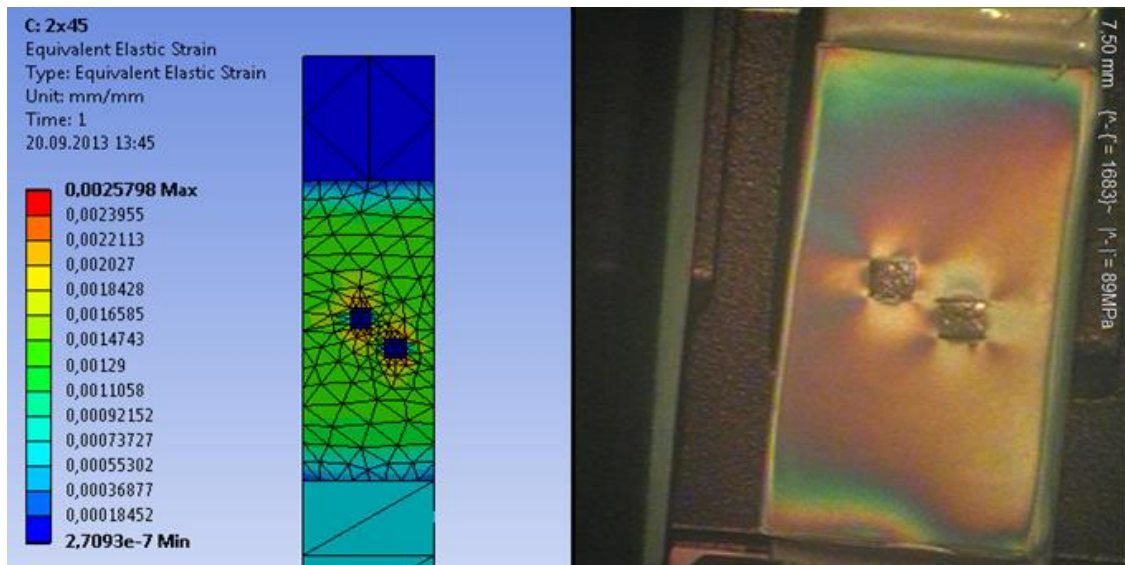Fig. 11. Three inclusions sample.

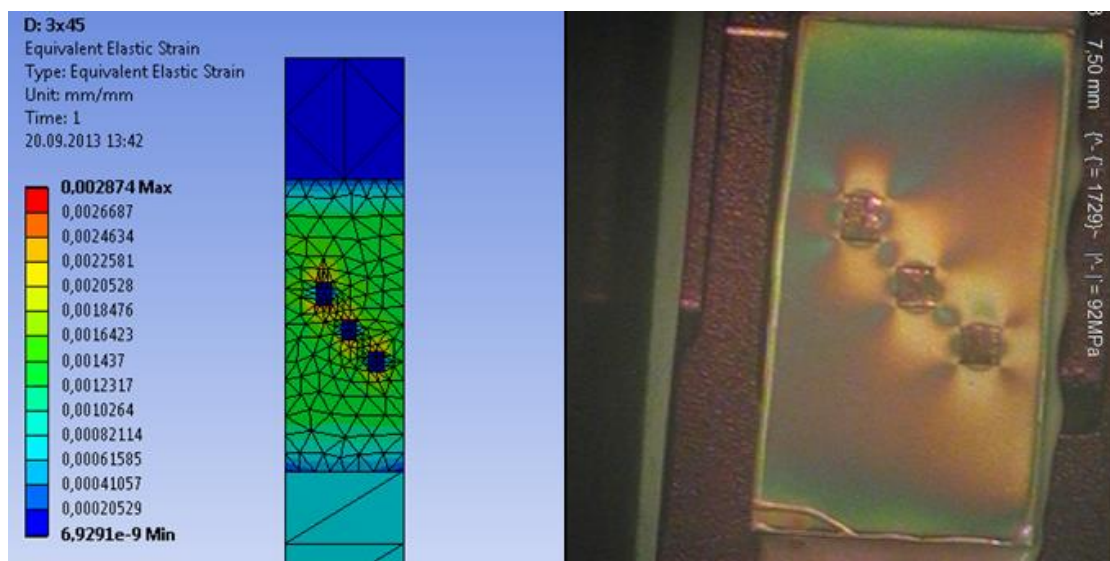Fig. 12. Two inclusions 45º sample.

Fig. 13. Three inclusions 45º sample.

4. Conclusions

Validation of the model was done by comparing the strain distribution between the numerical models and the experimental results. There is no visible and relevant difference between the numerical models and the experimental results, thus validating the numerical model. The finite element method is suitable for the determination of the effect of metal inclusion in plastic materials

Acknowledgements

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