New trends in ECT applications from the MADEND project

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Abstract

In this paper we will present some applications drawn from a research project of national interest named MADEND (Methods and Applications of Non-destructive Electromagnetic Diagnostic). These applications concerns defect identification in metallic plate through Eddy Current Test, a survey on failure mechanisms in Au-Al junctions of integrated devices for automotive applications and analysis of civil building by means Electrical Resistive Tomography or Microwave Tomography.

Defects identification in metallic plates

We will present some remarks about the sensibility of non destructive tests used for detection of thin cracks in metallic plates and a particular technique used in order to check the defect deepness respect to the surface. In the project specified above we have realized and optimized an experimental system for defect identification in metallic plate and we have used them for three benchmarks analysis described in the figure 1.

On an aluminium plate with 4 mm of thickness there is an artificial (perfectly insulating) defect with cylindrical shape, his diameter is 1 mm and his height is 4 mm, 3mm and 2 mm respectively. The probe used is a coil placed on the metallic surface under test. For the benchmark # 2 and 3 the probe coil is placed in the opposite side respect to the cylindrical defect. This coil has 400 turns, 10 mm of height, 12 mm of inner diameter, 18 mm of outer diameter, 0.5 mm of lift-off and is electrically linked to a suitable balanced bridge circuit, and the voltage variation on the bridge allows the crack identification. We move the probe by means of a two dimensional automatic positioning system with 0.1 mm of resolution, for the voltage variation measurement we use a signal voltage analyzer with 1 μV of resolution, an amplified signal generator for the electrical circuit supply and dedicated software based on digital control. In particular the probe coil path and the acquisition time of each point measured it can be computer-controlled. This measurement system is the result of a sensibility study described in [1].

This experimental set-up are used for a validation of three different numerical procedure, the first is a finite element method based on a differential formulation. In particular we have used a numerical technique for the coupled resolution of the electrical circuit equations and of the finite element equations, for the probe coil impedance calculation. We have used a differential formulation and two kind of unknowns: magnetic vector potential on the total region, and the electric scalar potential only inside the metallic plate (eddy current region) [2].

The second finite elements numerical model is based on a integral formulation and on edge-elements shape functions. Integral formulations are interesting because they require to discretize the conductive domain only and automatically account for the regularity conditions at infinity. For linear materials, the numerical model is a system of linear algebraic equations with a dense coefficient matrix. The number of unknowns N depends on the mesh used to discretize the conductors and affects the accuracy of the numerical solution. As *N* is increased, the accuracy improves but the computational cost increases together with the memory occupation, thus setting a severe limit to the maximum value of *N* that can be considered. This problem has to be properly considered in ECT modeling because typical problems involve small defects in a conductive material, thus requiring fine discretizations of the conductive domain. The problem has been solved by developing ad hoc numerical formulations allowing to model volumetric defects contained into an a priori known region that is significantly smaller than the conductive domain [3] and fast solvers (Fast Multipole Method [4] and Precorrected FFT [5]).

The third is another procedure based on integral formulation named method of cells [6]. The solution of the benchmark problems has been also takled with a discrete approach, based on a geometric reinterpretation of the physical laws and of the constitutive equations for eddy currents. An algebraic formulation has been implemented, based on the circulation of the magnetic vector potential on edges and on a gauge function on the conductor nodes, to compute the impedance variation between defected and flawless conducting plates. Volumetric defects have been modeled comparing the results with those from the proposed benchmarks and with the numerical simulations of the integral and the differential FE formulations. Moreover, this formulation allows to efficiently treat also a zero thickness defect, approximating it as a non plane surface made of a collection of dual faces.

A comparison between numerical and experimental result is represented in figure 2. In this figure there is the voltage bridge variation versus the probe coil position.

The numerical and experimental procedure above allow the defect localization on the plane x-y on the metallic plate, now the new aim for our work is to assist the resolution of the inverse problem in order to check the defect deepness respect to the surface. The new data are performed by the harmonic analysis of measurement system response when the his feeding is a voltage pulse. The different penetration thickness of the eddy current and the different variation of the voltage bridge discriminate the defect deepness.

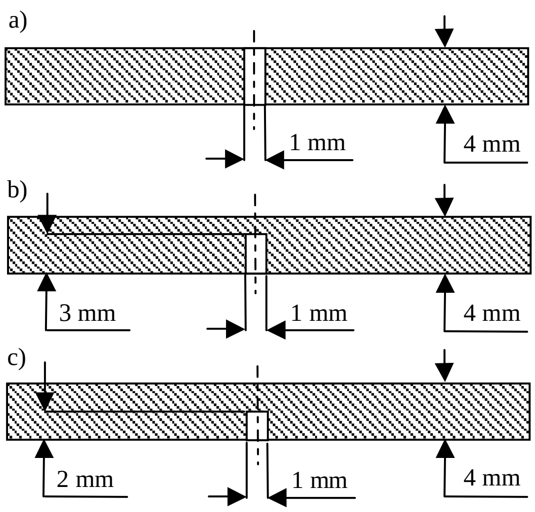

Figure 1. The benchmark problems.

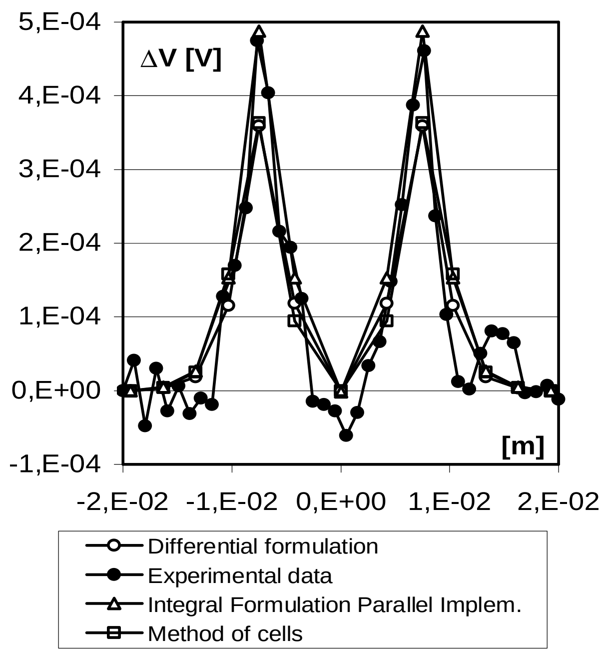

Figure 2. Comparison between numerical and experimental data for defect a) described in figure 1.

A survey on failure mechanisms in Au-Al junctions of integrated devices for automotive applications

In this section a class of power integrated-devices for automotive applications is considered, in the frame of a cooperation with ST Microelectronics (Agrate, Italy). For these systems requirements in terms of mean lifetime and operating conditions represent a challenge for current technologies. In particular, the increase of temperature, due to the current flowing through the Au-Al contacts between Al pads upon the Si die and the external Cu leads, stimulates the growth, by diffusion, of various inter-metallic layers. Moreover, when the value of specific current is high, mass transportation and consequent formation of interface voids are also observed. Both diffusion and electromigration cooperate increasing the electrical resistance of the contact and decreasing its mechanical strength. As a consequence, the degradation of the junction takes place up to its failure, as is clearly shown by electronic-microscope scan-pictures of the contact section. At the Package-Engineering Laboratory of ST Microelectronics, various test patterns have been developed for measuring the degradation of the Au-Al junction; the effect has been quantified in terms of lifetime, which is defined as the mean time to a prescribed increase in the resistance measured at the terminals of the junction itself. To this end, a known direct current has been injected into the junction at a constant external temperature; the resistance-time curve has been accordingly recorded. The experimental apparatus is based on a four-point method: the current is injected through a pair of terminals, while the voltage is measured across the no-load terminal pair, in order to neglect the self-resistance of probe wires. Results of measurements in terms of resistance variation of the junction vs time are represented in Fig.3, where all curves refer to the same outer temperature equal to 180 °C.

The reference value is the resistance at t = 0, which was around 60 $\mu\Omega$. For the sake of comparison, the resistance-time curve when no current is injected has been registered too; the latter represents the growth of intermetallic compound assisted by thermally-activated diffusion which follows approximately a parabolic law. In the other four cases, the injected current varied from 0.5 A to 2 A, corresponding to current density in the order of 10^4 up to 10^5 Acm^{-2}; always, a threshold over which the growth rate increases dramatically can be observed. Moreover, the time to this jump decreases when the value of current increases. All measurements have been repeated by varying the outer temperature; again, a similar effect of junction degradation has been pointed out severely.

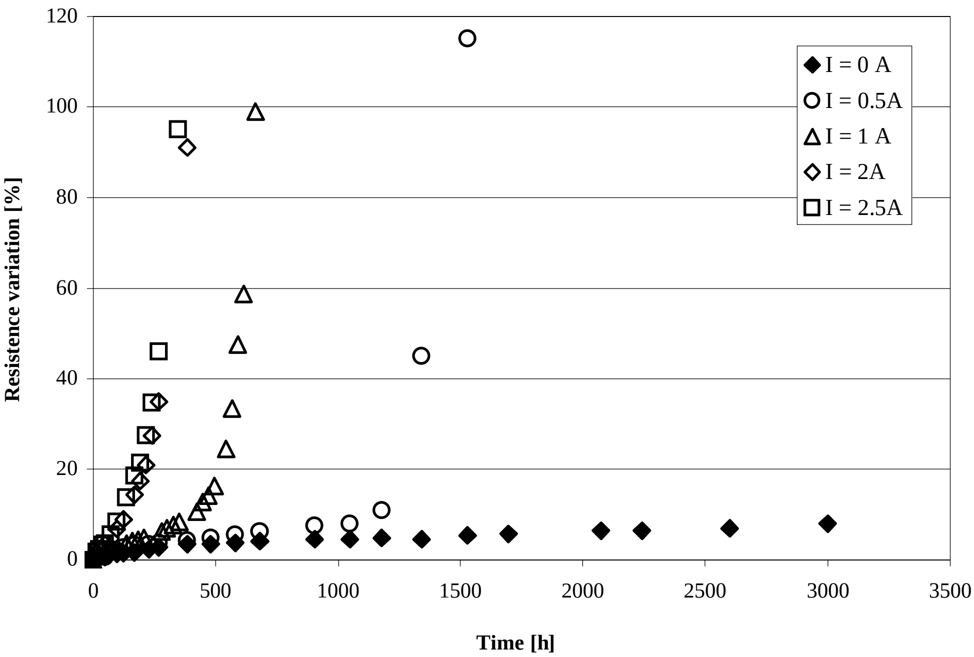

Figure 3. Experimental results.

Electromagnetic diagnostic of civil structures

In the last years, the Electrical Resistive Tomography (ERT), had been applied in several fields from geotechnical surveys to clinical diagnostics on human body, and has been considered lively in the international scientific community. The classical ERT is based on the measurement of mutual resistances among electrodes arranged externally to the specimen under test. Other cases of remarkable applicative interest, the inclusion is characterized by an high conductivity compared with the surrounding domain and, in addition, is “electrically accessible”, and can be profitably included among the electrodes of the measurement system. As an applicative example, the detection of damages due to micro-landslides during the concrete casting for a pile is considered, showing advantages of DERT trough numerical simulations [7][8].

An other technique performed is based on microwave scattering phenomena. Usually in the walls and other structures of old and historical buildings it is necessary to introduce a particular kind of mortar in order to improve their mechanical characteristics, but the positions of this material inside the wall is unknown because invisible from external. This fact prevent to know the effectiveness of reinforced work. Because the mortar injection is realized by means high pressure it's possible to damage the important architectural or artistic structure present on the wall as paintings and bas-relief if the reinforcing operation is not stopped just in time. We will present in this work original techniques based on the electromagnetic tomography by means of high gain antennas at 1 GHz. In the figure 4 we show a picture of the our measurement set-up in a semianecoic and shielded chamber. We have built a brickwork with empty space then we have introduced the mortar with conductive particles in three different positions. In the figure 5 we show the results of a two dimensional scan by an automatic position system an two horn antennas with different polarization and orientation respect to the wall surface. The first antenna is used for electromagnetic field generation, the second for the electromagnetic field reception, the scattering phenomena allow the mortar identification. In the figure 5 the mortar position is highlight inside circles.

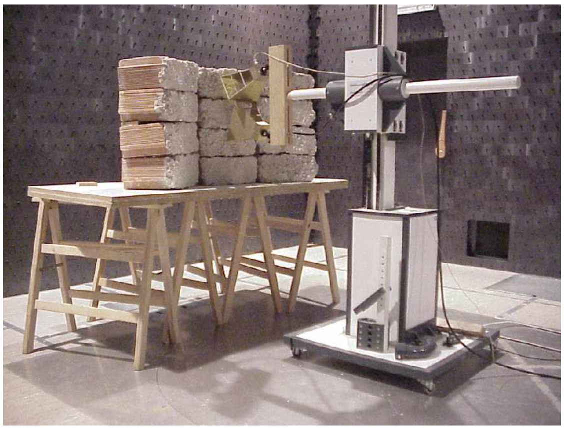

Figure 4. Measurement set-up in a semianecoic and shielded chamber.

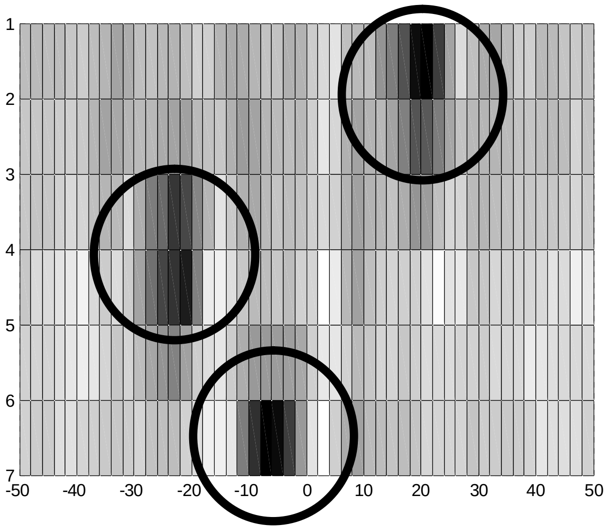

Figure 5. Result of a two dimensional scan

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