NON-DESTRUCTIVE DETECTION OF PREPREG DEFECTS IN MULTILAYER PCB

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Abstract - Prepreg is a composite and often is highly anisotropic in nature. This coupled with his resistive properties, severely restricts detection of deeper defects in multilayer PCB, where it finds application.In this work, a systematic methodology has been presented for the detection of defects in prepreg isolating layers. Different test samples with artificial defects of different sizes and depth were fabricated for experimental studies. Both one-sided and two-sided lock-in thermography test methods were explored.As a result of numerical modeling, of the heat conduction problem in PCB with different constructions, the optimal combination of parameters of the thermographic non-destructive procedure at zero noise has been developed for each specific case.Experiments were conducted to verify the corresponding theoretical predictions.

Keywords - Printed Circuit Board, Nondestructive Testing, Thermal Image, Prepreg.

I. INTRODUCTION

In recent years, the demand for multilayer printed circuit boards in the field of applied communications, base station, aviation, military, etc. [1].

In the production of multilayer boards (MLB), as well as substrates for multi-chip modules type L (MCM-L) in the stack of the many inner sheets of prepreg and cores can occur defects during pressing, such as delamination, bubble residues, sliding sheets, resin voids [2]–[3].

Providing strong substrates and boards is a guarantee for the high reliability of electronic modules. Therefore, quality control, especially non-destructive, reduces costs and increases the efficiency of electronic equipment. Recently, the application of thermal control in the production of MLB has quickly become necessary [4]–[7]. Infrared cameras are used for the implementation of non-destructive thermography control and diagnostics.

Passive thermographic control is mainly used to detect faults and defects of powered PCBs. This is the case when the defects are active, i.e. they can emit or absorb heat energy. In this way, the following can be detected, for example, poor assembly, defective components, incorrectly located elements of the board or substrate, as well as to assess the overall structure and cooling system [8] –[9].

Active thermography is used to diagnose subsurface defects when the defects before the control are at the same temperature as the ambient temperature [10]–[13]. This allows quality control before assembling the board.

In the present study, the method of optically active thermography was used to detect defects occurring in the insulating prepreg layers of PCBs [10]. Thus, hidden defects of thinning of the insulation layer, air inclusions, poor adhesion, cracks, cavities, etc. can be detected. The main steps and requirements for the implementation of non-destructive diagnostics of defects in the inner prepreg layers of multilayer PCBs are discussed. Test specimens with artificially formed defects were prepared and tested using active thermography. The main steps in setting up the basic diagnostic procedure are shown.

II. PREPREGS IN MULTILAYER BOARDS MANUFACTURING

A. Prepreg for PCB

The use of prepreg in printed circuit boards manufacturing is due to the fact that it is easy to implement, does not require specialized technical training of staff, and contributes to better waste management during the production process. Prepreg is a reinforcement of FRP - fiberglass impregnated with resin. Prepregs are insulators that bond core and copper foil and support the production of a strong printed circuit board. It is also used in the manufacturing process of flexible or rigid-flexible circuit boards. The presence of areas of poor adhesion and air inclusions or voids in the bonding area is crucial for the printed circuit boards to function according to specifications. It is mainly responsible for the proper bonding of the layers, the insulation between them, as well as for reducing the total weight. The thickness of the prepregs after bonding must be at least twice the thickness of the copper being embedded. The required thickness of the printed circuit board depends on the type and combination of prepreg layers. The resin content affects the thickness of the piece of laminate when pressed, as well as parameters such as coefficient of thermal expansion (CTE) and dielectric constant. The quality of drilling and etching is also influenced by the resin content of the prepreg. Lamination is performed by heating the prepreg under pressure to liquefy the resin and form a flow of resin. The amount

of flow that occurs depends on the pressure and the heating rate. For some time the resin remains fluid, after which it gels and cannot flow freely. The actual resin flow is significantly affected by the laminating conditions. The amount of this actually available flow influences the realized interlayer connections or interlaminar bond and, accordingly, the efficiency of the connecting prepreg. An important feature is that in the literature and technical documentation there are no data on the thermophysical parameters of the prepreg before and after its pressing in a stack.

An important feature is that in the literature and technical documentation there are no data on the thermophysical parameters of the prepreg before and after its pressing in a stack. Infrared thermography can be used as a method to measure thermal diffusivity, effusivity, or conductivity of the prepreg [14]. The thermophysical parameters of the investigated prepregs were measured in advance and the obtained data were used in the modeling of thermographic regimes in the process of optimizing the testing procedure.

B. PCB Test Sample Manufacturing

Before the test structure was developed, a design was made in which the thickness of the dielectric and conductive layers was determined, as well as the topology of the conductive layers. Fig. 1 shows the seven layers test structure. The structure is symmetrical to the prepreg layer with defects. Two outermost layers of the test sample surfaces are coated with a layer with a high emission coefficient to correct the emissivity during thermographic measurement.

FR4 material with a dielectric thickness of 200 μm as core and a copper layer thickness of 120 μm were used to fabricate the shown test structures. Two PCBs with a certain topology are formed from this material in order to realize different options available for defects in the prepreg. In the next process, these two boards are glued (laminated) and so the real test structure is made, corresponding to the preliminary design. Prepreg Isola 2116 was used to glue the two cores together as shown in Fig.1.

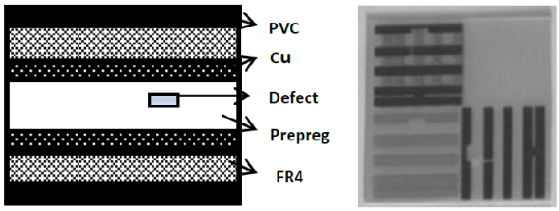


Fig.1. Cross section of a simplified test PCB structure with shown layers and a defect in the prepreg layer, and a picture of the same sample without PVC layer.

The mode of the lamination process includes a preheating phase of the press, which starts from room temperature to 180 °C. After completion of this phase, the multilayer structure is placed between the press plates of the press and the Prepress phase begins. During this phase, the pressing and heating of the individual layers and the Prepreg material begin. The phase is characterized by the fact that the temperature required for the polymerization of prepreg is reached, but the pressure is reduced. This is done in order to expel the trapped air bubbles between the hard areas and the already softened prepreg material. The phase lasts about 20 minand the pressure is 110 N/cm^2. The third phase is the main phase of lamination in the press. Its temperature is constant (180 °C) and the pressure is increased to 150 N/cm^2. The duration of phase 3 is about 60 min. During the fourth phase, the laminated multilayer structure should not be cooled too quickly. It is also important that the pressure of the press does not decrease during cooling. This phase lasts until the temperature of the structure is reduced to a minimum of 50 °C.During the lamination of the two printed circuit boards a LPKF Multipress II lamination press was used. The thickness of Prepreg 2116 after pressing is 105 μm for one layer.

C. Research methodology

In order to cover the possible variants of testing defects in prepreg, modeling of three different sizes and depth of defects and three different values of prepreg thickness (realized with one, two, and three sheets of prepreg) was performed. Below the results of modeling of defects from air inclusions in a prepreg insulation layer realized with two and three sheets of prepreg materialare illustrated. The optimization of the procedure was performed by lock-in thermography, on the surface closer to the investigated prepreg layer, and periodic (harmonic) heating with a halogen lamp. Modeling was performed for different test variants in terms of lock-in frequency, the number of periods, the frame rate of the chamber, and parameters of the halogen heat source such as average heat flux through test sample, etc.

In Fig. 2 a model of two defects in the prepreg insulation layer is shown. The larger defect is located below one layer of copper tracks on one core and above copper tracks on the second core. The second defect is located so that above it and below it there are no copper tracks. Both defects are marked in white.

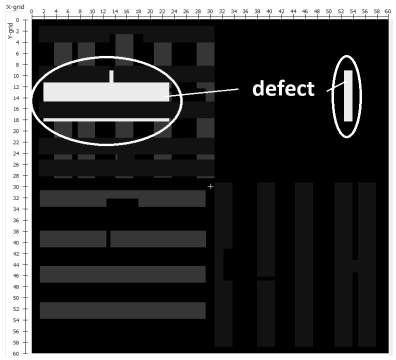


Fig.2. Model of a test sample with defects into isolating prepreg layer.

The optimal prototype of the non-destructive thermographic testing procedure has been developed to finish with a binary defect map. The map is to be created for accepted levels of false alarm P_f and correct detection P_c. The P_f and P_c values were determined for any pixel (i, j) by analysing the location of the single temperature value T (i, j) within two histograms-of a defect and non-defect area.

A specific defect map can be made by assigning a binary value to the (i, j)-the pixel respectively:Amplitude $A(I,j) = 1$ if $P_c(I,j) \geq P_{c.,norm}$ and $P_f(I,j) \leq P_{f,norm}$, otherwise $A(I,j) = 0$. We recommend $P_f = 5\%$ and $P_c = 80\%$ as a common normative values.

Fig. 3 shows the measuring setup for lock-in thermographic testing. The infrared camera FLIR SC640, 500 W halogen lamp Hedler H25s with adjustable light intensity, sensor Hukseflux FHF02SC with read-out datalogger Hukseflux LI-19, and temperature/humidity meter (THM) JT-07CRL can be seen. The infrared camera and halogen lamp are connected to the thermography control and synchronization module. These are not shown in the photo. IR-NDT software is used to thermogram sequences capture, and process.

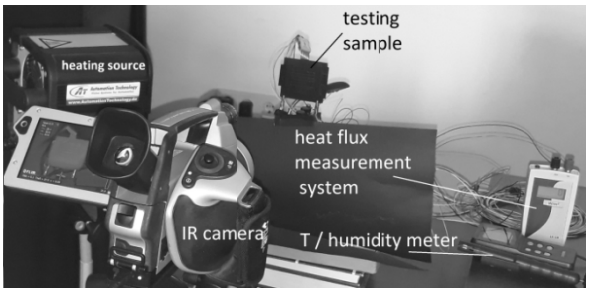
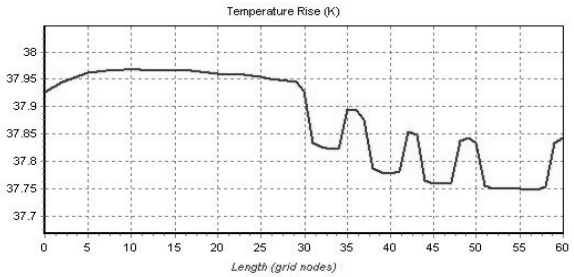


Fig. 3 Lock-in thermography experimental setup

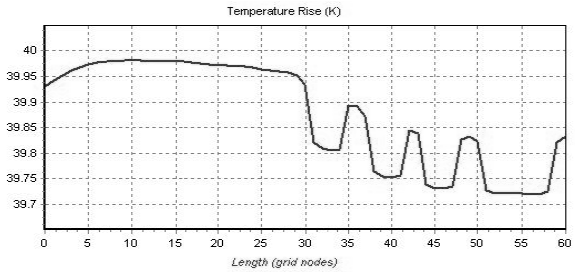
III. EXPERIMENTAL PROCEDURES AND RESULTS

The results of modeling and experimental verification show that artificial defects in the prepared experimental samples can be successfully detected in testing by lock-in thermography.The results of modeling and experimental verification show that artificial defects in the prepared experimental samples can be successfully detected in testing by lock-in thermography.Fig. 4 shows the surface temperature profiles of the considered samples under the same test conditions but at different thicknesses of the insulating prepreg layer. From them, the size of the defects can be determined. It is noticed, that the thinner the layer, the higher the temperature.The simulation of the thermographic procedure allows the selection of the optimal parameters for the non-destructive system in terms of minimizing noise, improving contrast, and allowable heating of the sample material. An increase of 2 °C on the surface over the defects is observed.

On Fig. 5 the thermograms in a grey palette 90 s after the start of heating for the same two cases are shown. The contrast is more pronounced when using a colour palette.

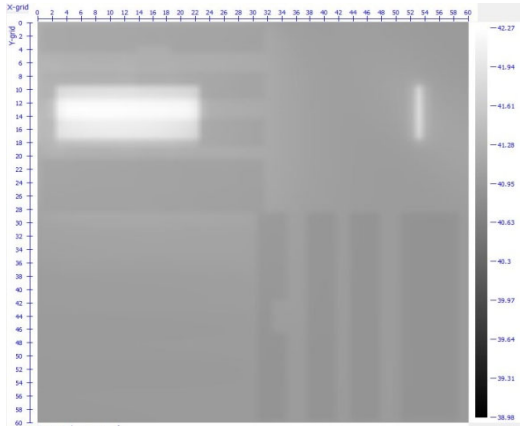


a) defects in isolated layer pressed of three prepreg sheets

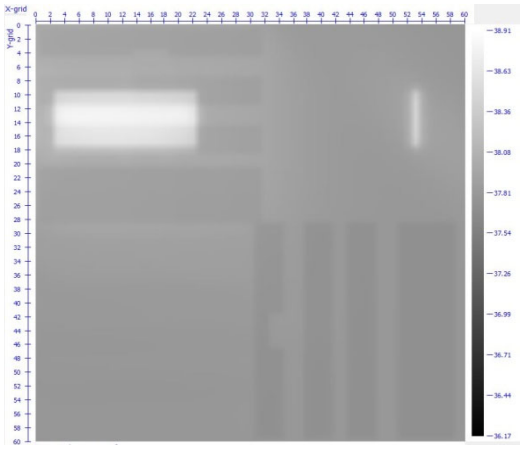


b)defects in isolated layer pressed of two prepreg sheets

Фиг. 4.Temperature profiles



a) defects in isolated layer pressed of two prepreg sheets



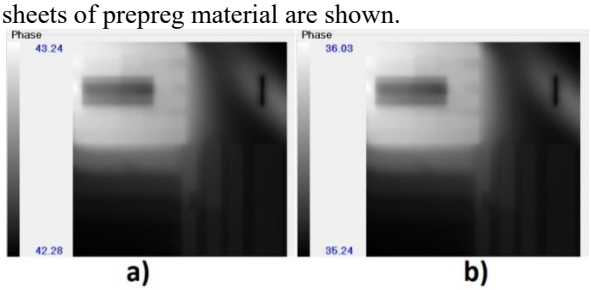
b) defects in isolated layer pressed of three prepreg sheets

Фиг. 5. Simulated thermograms 90 s after the start of lock-in thermography

When the halogen lamp (the heating source) is synchronized with the infrared camera, and if the lock-in frequency is low compared to the frame rate, synchronous narrow two-channel correlation is used as an optimal digital demodulation algorithm to achieve short computational time and high accuracy. This method has the advantage that it does not require storage of the infrared image and can be performed in real time.

Applying the pixel-based Fourier transformation to time behaviour of temperature allows enhancing subtle differences between temporal evolutions of temperature in different sample areas. It is known that the result of the Fourier transformation is a set of two images (called phasegram and ampligrams) obtained for a particular Fourier frequency. Typically, images of phase (phasegrams) are most noise-resistant, particularly, in the case of uneven heating.

On Fig. 6 phasegrams of the same defects formed in insulating layers, forming by pressing two and three sheets of prepreg material are shown.



Фиг. 6.Phasegrams: a) isolated layer pressed of two prepreg sheets; b) isolated layer pressed of three prepreg sheets

Subsurface defects in samples are better detected by phasegrams than by raw thermograms [12].

On Fig. 7 phase diagrams of samples with two prepreg insulation layers with defects are shown. In phase diagram (a), defects are observed in the layer closer to the surface that was tested with the infrared camera. In phase diagram (b) defects in the other layer are observed when the observation is from the opposite side. One-side thermographic control was performed in both measurements.

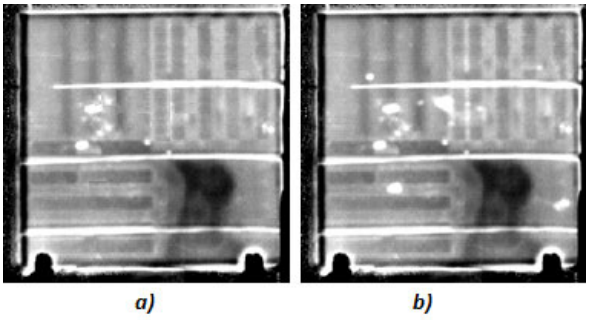


Fig. 7Phasegrams of sample with two prepreg isolated layers with defects.

Забелязват се едни и същи дефектни зони, дължащи се на наличието на дефекти с голяма дебелина.

IV. CONCLUSION

The production control of the prepreg dimensions requires data collection in production for a certain period of time. Infrared thermography can allow the non-destructive determination of the layer thickness and eliminate this need.Experiments were performed with optimized parameters in a one-sided testing method. Defects up to a depth of the order of approximately 3 mm were detectable in raw IR images by a one-sided method. It was found that the two-sided testing method can be useful for the detection of defects deeper than5 mm..

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