3D-Microscope-ESPI: Potential for Displacement Analysis on Small Areas

Introduction

Laser speckle interferometry as full field and non contact measuring technique offers highly interesting opportunities for deformation analysis on components. While its application in material testing and material research has already achieved an interesting level of acceptance in research and industry the application on very small components has been restricted. Present problems involve speckle size, optical access, decorrelation at object translation, etc. On the other hand, the potential of speckle interferometry to solve micromechanic measuring problems seems very high. First designs of ESPI system capable of measurement of very small areas have been designed and applications been tested.

Microscopic 3D-ESPI

The principle of speckle intereferometry allows the measurement of complete deformation fields. The combination of several illumination directions and one observation direction allows the determination of the threedimensional deformation field. A principle set-up is shown in fig. 2.

Therefore, principally, a standard 3D-ESPI system can be used for the purpose of measurement on very small objects by simply exchanging the observation lens by a macro lens with macro extension tubes. Conventional macro lenses and macro tubes offer the possibility to achieve measurement areas down to 1 x $1mm^2$ without changing the performance of the system, significantly.

Fig. 2: Standard 3D-ESPI system in a tensile testing machine to test miniature weld specimen.

Miniature weld measurements

A standard 3D-ESPI system in a tensile testing machine in order to measure strain distributions on a miniature welding specimen is shown in fig. 2. A tele lens with macro converter serves for enlargement of the field of view. The width of the specimen in this example is approx. 1.4 mm. The deformation data are recorded at a local resolution of approx. 0.01 mm per camera pixel, fig. 3. Since the speckle measuring technique is based on the principle of the speckle "noise", we can realistically calculate with a local resolution on the surface of 0.1 mm. The displacement sensitivity of the measurement is not effected by the size of the field of measurement and still is in the range of 10 to 100 nm in out-of-plane and in-plane direction.

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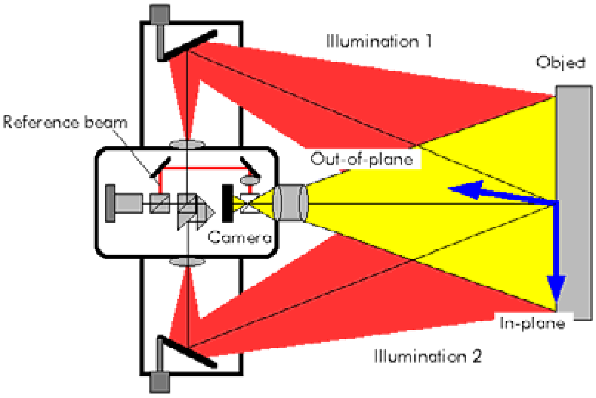

Fig. 2: Principle of threedimensional measurement with speckle interferometry

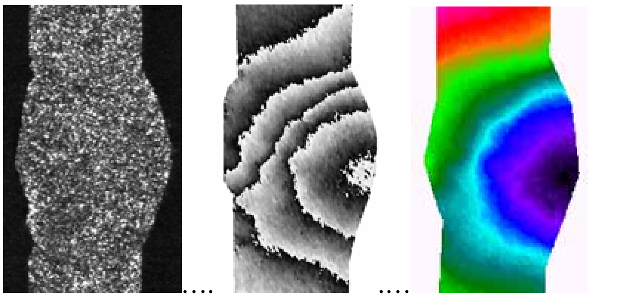

Fig. 3: Live image (left), phase map (center) and measuring result (right) of a miniature aluminum welding specimen: the width of the specimen is just 1.4 mm.

Residual stress measurement

The hole drilling method is well accepted as technique for residual stress determination in components. Nevertheless, the laborous application of strain gauge rosettes in the drilling area limits the application of this technique to flat surfaces. First experiments with a miniaturized 3D-ESPI system have been carried out. This system, shown in fig. 4 has originally been designed for the replacement of strain gauges. It delivers 3D deformation and strain values on the surface of the component. For measurement on very small surface areas, the observation optics has been modified. For residual stress measurement, the Microscopic ESPI System was placed on a translation stage together with a miniature drilling machine. At each level of drilling depth the ESPI system was positioned in the original position to compare the state of deformation with the earlier state. From the complete set of 3D deformation fields, the strain values at the corner of the hole were calculated and plotted versus the drilling depth, see fig. 5. The potential of this technique is the ability to measure also on curved surfaces and to significantly reduce the preparation time for residual stress determination.

Fig. 4: Residual stress measurement with a Microscopic ESPI system and the hole drilling method

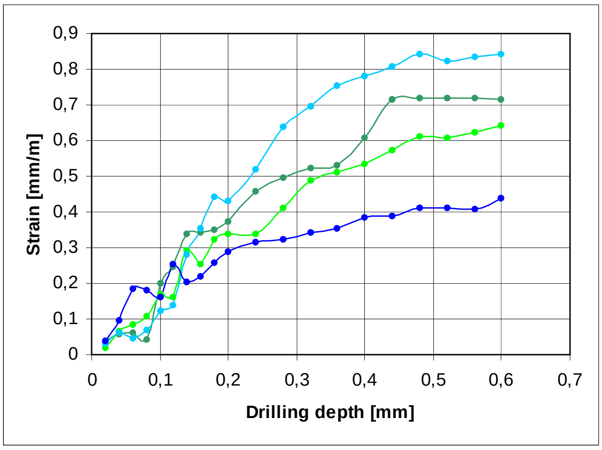

Fig. 5: Strain values at the right, left, upper and lower corner of the hole developing at different levels of drilling depth.

Solder joint on chips

Electronic chips are becoming more compact, fig. 6. More and more transistors are packed in the same area, producing significant heat in the chip. The solder points fix the chip to the substrate and hinder the thermal expansion of the chip. A crosscut through an electronic module illustrates fig. 7. Therefore, significant stresses can be introduced by the operation of the chip. Designers of chips need to understand the mechanical behaviour and quality of their chip design.

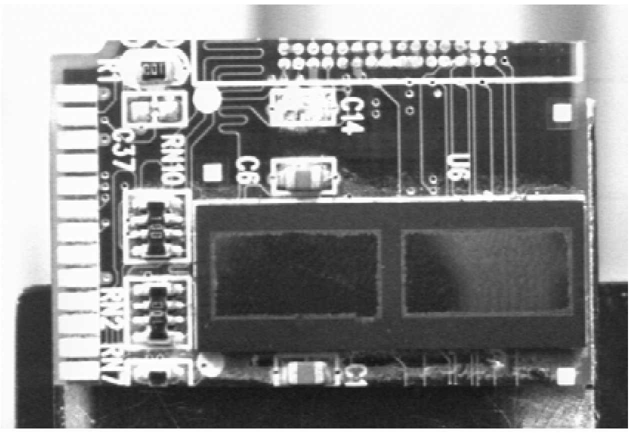

Fig. 6: Microelectronic chip.

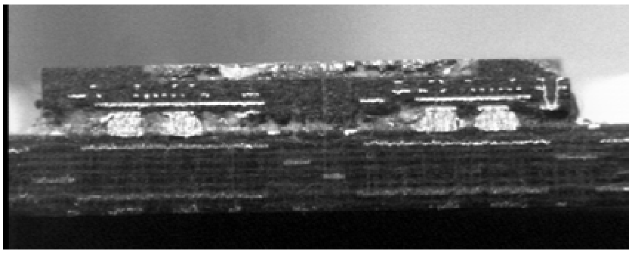

Fig. 7: Crosscut throug chip. Thermal expansion causes stress concentrations at the solder points.

Therefore thermal loading tests have to be carried out on the chips. ESPI offers the unique possibility to measure both, the in-plane and out-of-plane deformation and strains of the chip without surface preparation. The Microscopic 3D-ESPI system is positioned in front of the surface to be measured and records the threedimensional deformations during the heat-up or cool-down process. As example, fig. 8 shows the deformation field at a cool-down process. The colours represent the out-of-plane deformation, while the in-plane components are described by the direction and length of the black arrows. All data are quantitatively measured and stored.

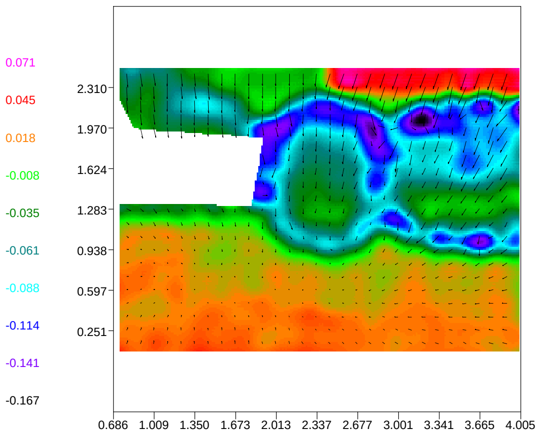

Fig. 8: 3D-deformation field of one single solder joint. The colors indicate the out-of-plane displacement in micrometers, the arrows the in-plane components of the displacements.

High local resolution

The examples show measuring fields of few millimeter and local resolutions down to 0.01 mm. The principal limit of the local resolution with speckle measuring techniques is determined by the wavelength of the used laser light. Therefore, the present state of development has not reached a limit and will be promoted to smaller components and fields of view.

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