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Failure of silicon substrates embedded in epoxy resin

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Abstract

For cyber physical systems and structural health monitoring sensors have to be embedded in a material. Therefore two types of inlays (sensors) can be used: conventional inlays made of silicon as substrate material or new developed inlays made of non-conventional substrates. In this paper we will focus on embedding conventional inlays made of mono crystal silicon. Inlays had been embedded in test specimens for pull and bending tests to measure the ultimate tensile and bending strength. In the pulling tests the ultimate tensile strength decreases dramatically in comparison to pulling tests where no inlay is embedded. For the bending tests the results were quite different: If the inlay is embedded in the neutral fiber there is nearly no degradation of the ultimate bending strength. But when an inlay is embedded between the neutral fiber and the outer edge of the test specimen the ultimate bending is less than half of the ultimate bending strength of tests specimen with no inlay.

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1. Introduction

Getting measurement quantities out of material is described by the term “Structural health monitoring” [1,2]. Therefore a sensor has to be placed on the surface of the material or has to be embedded in the material. For the first possibility many different concepts have already been developed. [3] While these sensors are placed on the surface the setup is not very difficult in contrast to embedding a sensor in a material which is much more difficult. Reducing mechanical weakening of the structure, leading out electrical interconnections and joining a sensor with the material

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are only a few challenges which have to be solved when embedding a sensor. Different sensors have already successfully been embedded in different materials like carbon fibre [4,5] or titanium alloys [6,7].

In [8] we have theoretically investigated the mechanical behaviour of sensors – forthwith named inlay – embedded in a material – forthwith named matrix: When the Young's modulus of the inlay is much higher than the Young's modulus of the matrix the whole structure of matrix and inlay is mechanically weakened. In this paper we want to proof this by experiments. In common fabrication MEMS are produced on mono crystalline silicon substrates; thus it seems to be the easiest way to embed those sensors in materials. This is why we chose mono crystalline silicon without any sensor function for the inlay. To have a different Young's modulus in contrast to the inlay for the matrix a common epoxy resin was used [9]. By pull and bending tests the ultimate tensile and bending strength were investigated.

2. Experiments

2.1 Design of the test specimens

The test specimens were designed as illustrated in fig.1a and is in dependence on DIN ISO 527. For the inlays, bars made of silicon wafers with a thickness of 520µm, 380µm and 220µm were used. The dimensions of the test specimens and the inlays are given in fig. 1. For tensile tests the inlays were placed in the middle of the matrix. In the bending case two different positions of the inlays were investigated because the neutral fiber has to be taken into account: Inlays were placed in the neutral fiber as well as outside of the neutral fiber with an eccentricity of 1mm (see fig. 1b).

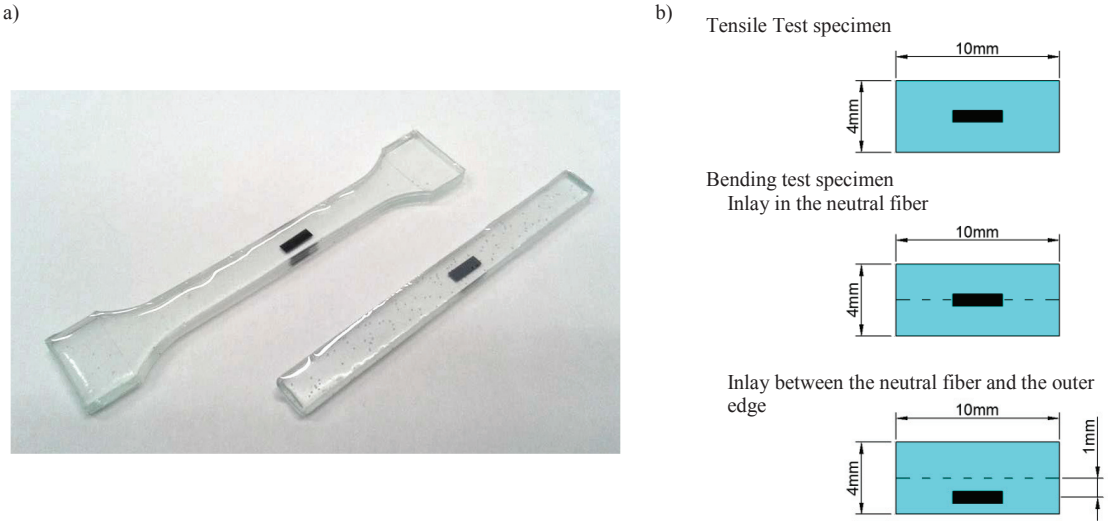

Fig 1. (a) left: tensile strength specimen with a length of 112mm respectively 8mm for the inlay, right: bending test specimen with length of 80mm respectively 8mm for the inlay, (b) cross section of the test specimens

2.2. Fabrication of the test specimens

In the beginning the inlays are diced out of the wafers. For silicon <100>-wafers were used and the dicing direction was <110>-plane. The inlays are cleaned by purging them with acetone and isopropanol.

The test specimens are fabricated by casting the epoxy resin. Therefore test specimens are laser cut and by forming those with silicone molds are build up.