Integration of strain gages into fibre composite structures
Strain Gage for Structural Integration
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1. Introduction
2. Research and development
3. Integration and manufacturing process
4. Examples of use
Content

1. Introduction

2. Research and development

3. Integration and manufacturing process

4. Examples of use
1. Introduction

Sensors for integration

<table>
<thead>
<tr>
<th>Sensor Effect</th>
<th>Sensor Type</th>
<th>Measuring Principle</th>
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</thead>
<tbody>
<tr>
<td>point</td>
<td>directional</td>
<td>ohms</td>
</tr>
<tr>
<td></td>
<td>strain gage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>piezo fiber module</td>
<td>piezoelectric</td>
</tr>
<tr>
<td></td>
<td>piezo-plate</td>
<td>piezoelectric</td>
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<tr>
<td>line</td>
<td>directional</td>
<td>optical</td>
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<tr>
<td></td>
<td>fiber bragg sensor</td>
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<tr>
<td></td>
<td>PVDF-wire</td>
<td>piezoelectric</td>
</tr>
<tr>
<td>area</td>
<td>directional</td>
<td>ohms / piezoelectric / optical</td>
</tr>
<tr>
<td></td>
<td>sensor grid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>film sensor</td>
<td>piezoelectric</td>
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</table>
1. Introduction

HBM - competence partner for composite materials

Sensor
- embedded strain gages

Amplifier
- MGCplus

Software
- One software

Interrogator
- combining two different physical principals
Composite materials are used in...

...nearly every sector of industry

Aerospace
Automotive
Motor sport
Big vehicle bodies (trains, trucks, buses)
Marine
Wind craft
Sport articles
Infrastructure and buildings (repair of buildings, GFRP bridges)
Medical technology (human prostheses, x-ray tables)
1. Introduction

Reasons for the development of a special strain gage …

… for composite materials

Material properties
- high strains of composite materials - up to 4%
  - fatigue limit of strain gages 0.1%
- complex component geometry and fabrics (e.g. sandwich structures)
  - difficult or impossible accessibility
- possibility of applying the strain gage during the manufacturing process

Market development
- increasing use of composite materials
- development trend on “intelligent structures”
  - increasing demand on composite specific sensors
1. Introduction

Advantages of the integration of SG:

- adjustment of the strain level for bending load
- measurement at usually hard accessible locations (bonded components)
- improved aerodynamics - wiring inside the structure
- protection of the strain gage
- cost-saving by applying the SG during the manufacturing process
1. Introduction

2. Research and development

3. Integration and manufacturing process

4. Examples of use
2. Research & Development

General challenges when integrating sensors:

- compatibility of composite and sensor materials
- measuring behaviour of the embedded sensor
- handling during the manufacturing process
- accessibility of the embedded sensor
- positioning and alignment

HBM solution:
2. Research & Development

The “pin-concept”

Function of the pins:
• leading the electrical contacts of the embedded SG out of the laminate
• fixing the SG during the curing process

Advantages of the pin:
• no wiring inside the laminate
• manufacturing compatibility
2. Research & Development

Investigation on the adhesive connection between the carrier material and the matrix resin

- Integration of differently pre-treated polyimide films
- Determination of the interlaminar shear resistance ILS and the interlaminar fracture toughness $G_{1C}$

**ILS-Test**

**$G_{1C}$-Test**
2. Research & Development

Determination of the interlaminar shear resistance ILS

\[ \tau_{ILS} = 0.75 \cdot \frac{F}{b \cdot h} \]

Interlaminar shear resistance ILS following DIN EN 2563

![Image of testing apparatus](image-url)
2. Research & Development

Determination of interlaminar fracture toughness energy $G_{1c}$

Interlaminar fracture toughness energy $G_{1c}$ following DIN EN 65563

\[ G_{1c} = \frac{W}{\Delta a * b} \text{ in } [J/mm^2] \]
2. Research & Development

Investigation of integrated strain gages in multi-directional tensile specimens

Stacking sequence and orientation of the strain gages:

<table>
<thead>
<tr>
<th>Layer number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<th>10</th>
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<td>Fibre orientation</td>
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<td>±45°</td>
<td>0°</td>
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<td>0°</td>
<td>±45°</td>
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<td>90°</td>
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<tr>
<td>Measuring grid orientation</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>±45°</td>
<td>90°</td>
<td>90°</td>
</tr>
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</table>
2. Research & Development

Tensile Test - GFRP-Specimen

Comparison of surface mounted and embedded strain gages
2. Research & Development

Tensile Test - GFRP-Specimen
Comparison of surface mounted and embedded strain gages
2. Research & Development

CFRP tensile shear specimen – lay-up ±45°
2. Research & Development

Investigation on the concept of contacting pins ...
... with respect to fatigue strength / load cycle count

3-Point bending test: Strain gage integrated in the neutral axis of the laminate
-> max. shear stress at the base of the pin (interlaminar)

4-Point bending test: Strain gage integrated beyond the neutral axis
-> axial strains knit on the pins (intralaminar)

Laminate set-ups:
uni-directional multi-directional 4-point bending CRFP specimen
half bridge circuit + compensation specimen
2. Research & Development

Determination of the fatigue life of embedded strain gages ...

... following DIN 2536

Result:

Fatigue life, at reference temperature using a multidirectional CFRP sample.
Reached nr. of load clyc. \( L_W \) at alternat. strain \( \varepsilon_W = \pm 1000 \, \mu m/m \) a.

- variation of zero point \( \varepsilon_{\text{z}} \leq 100 \, \mu m/m \)
- variation of zero point \( \varepsilon_{\text{m}} \leq 300 \, \mu m/m \)

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<thead>
<tr>
<th></th>
<th>5 000 000</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>10 000 000</td>
</tr>
</tbody>
</table>
Determination of the fatigue life of composites

... with embedded strain gages
Specifications of the strain gage LI66-10/350

L = linear strain gage
I = integration

- temperature response: $\alpha = 0.5 \times 10^{-6}/^\circ C$
- measuring grid size: 10 mm
- nominal resistance: 350 $\Omega$
- covering / carrier foil: polyimide
- measuring grid material: constantan
- dimensions (l x w): 22 x 10 mm
- max. curing temperature: 200 °C

Pin:
- material: brass
- finish: gold on nickel
- pin length: 15 mm
- pin diameter: 0.7 mm
Advantage of the type 1-LI66-10/350

Layout:
• reinforced solder tabs
• larger distance between solder tabs to the measuring grid
• solder tabs outside the influences to the measuring grid

Example of a typical strain gauge-Layout (typ 1-LY41-10/350)
2. Research & Development

Special features of the strain gage LI66-10/350

Layout:

- extended distance between measuring grid and contact pins
- carrier material on top – “inverse” application possible
- pre-treatment on carrier and covering material
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4. Examples of use
The strain gage can be used for prepreg and resin injection method.

Basic manufacturing configuration with vacuum:

- laminate plate
- mold
- strain gage
- contact pin
- covering film
- vacuum bag
- tube to vacuum pump
- vacuum connection
- vacuum sealing tape
- fleece
- pin cover
3. Integration and manufacturing process

Alignment and fixing of the strain gage

**Application on the surface**
- marking the surface
- fixing the strain gage with tape

**Application on uncured composite materials prepreg**
- positioning by using e.g. a template
- fixing due to the tack of the material

**Application on uncured composite materials fabrics**
- positioning by using e.g. a yarn which is fixed to the mold (large components)
- use of binder material for pre-fixing the strain gage
3. Integration and manufacturing process

Integration method depending on the material and application

- **manufacturing process with fabrics**
  - stacking the fabrics on top of the strain gage – pins pierce through the following layers

- **manufacturing process with prepreg**
  - “inverse” application - pins are pushed into the already stacked material
3. Integration and manufacturing process

1. Applying the binder powder
2. Positioning the strain gage
3. Fixing the strain gage with binder powder
4. Applying further fibre mats

5. Pins protrude from the peel ply
6. Shortening the pins
7. Applying the foam cover
8. Configuration for further manufacturing
3. Manufacturing a structure with integrated strain gages

1. Applying the binder powder
2. Positioning the strain gage
3. Fixing the strain gage by warming up the binder powder

Depending on whether the whole structure is being fixed with the binding powder or not, a cover sheet can be used to help applying the powder locally in the area of the strain gage. When using prepreg material, the tack of the prepreg is sufficient to fix the strain gage.

The alignment and positioning can be done with a common measuring device such as a yardstick and right angle device. For large components a yarn can be clamped along the component for better orientation.

With a special electric iron the binder is melted and welds the strain gage to the dry fibre mat. A Teflon film prevents the direct contact of the electric iron with the binder.
After fixing the strain gage, the subsequent fibre mats are applied. The mats should be applied as parallel as possible to the structure surface to allow the pins to pierce through the mats easily.

The application of the peel ply is done in the same way as the fibre mats.

The picture above shows the pins protruding through the peel ply.
### 3. Manufacturing a structure with integrated strain gages

#### 7. Shortening the pins

Before applying the foam cover, the pins are shortened with a cutting tool to a length of about 2 mm.

#### 8. Applying the foam cover

The foam cover is applied on top of the pins with light pressure. The cover fulfils three major purposes:
- protection of the pins during further procedure,
- protection of the vacuum bag from damage through the pins,
- fixing the strain gage during the injection of the resin and during the curing.

#### 9. Configuration for further manufacturing

The further procedure depends on the manufacturing process – for example with fleece and vacuum bag.
3. Integration and manufacturing process

Preliminary test in cooperation with EADS Deutschland GmbH – EADS Innovation Works

Braided structure with integrated strain gages

pins piercing through the carbon filaments
Content

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4. Examples of use
4. Examples of use

Adjustment of the strain level for bending load

Fiber properties

<table>
<thead>
<tr>
<th>Fibers</th>
<th>E-Glass</th>
<th>Carbon HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>tensile modulus</td>
<td>73.000</td>
<td>240.000</td>
</tr>
<tr>
<td>[N/mm²]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tensile strength</td>
<td>3.400</td>
<td>3.600</td>
</tr>
<tr>
<td>[N/mm²]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>density [g/cm³]</td>
<td>2.6</td>
<td>1.78</td>
</tr>
<tr>
<td>strain to failure [%]</td>
<td>4.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Fatigue life of strain gages

\[
\frac{\varepsilon_{\text{integr. SG}}}{d - \frac{t}{2}} = \frac{\varepsilon_{\text{surface SG}}}{\frac{d}{2}}
\]

\(d = \text{lamine thickness}\)
\(t = \text{integration depth}\)

surface mounted SG
integrated SG
strain allocation

neutral axis

remaining zero point error (in μm/m)
- = 10
△ = 30
□ = 100
○ = 300
× = failure

number of load cycles \(n\)
4. Examples of use

Monitoring of repaired structures

Problem: noncontinuous filaments -> transmission of the force flow by the adhesive

Applications:
- repair of the structure and application of the monitoring sensor in one process step
- embedded strain gage is protected by the laminate from environmental influences

Exterior of the structure:
Aerodynamics is not affected by the strain gage or the measuring leads respectively.

Interior of the structure:
Measuring leads and electronics are located inside the structure.
4. Examples of use

Hybrid structures and measurement in bonding areas

Problem: No access to the application area after manufacturing

Applications:
- measurement of residual stresses
- monitoring of the strain transmission of bonded joints during use
4. Examples of use

Aerodynamic structures

Problem: Disturbance of the aerodynamics caused by surface mounted strain gages and wires

1. integrated or surface mounted strain gage
2. Pins lead through the laminate into the inside of the structure where they contact the measurement electronics
3. Measurement electronics

Applications:
- preservation of the aerodynamic properties
- measurement on fast rotating systems

e.g. helicopter rotor blade
4. Examples of use

Strengthening structures using FRP composite materials

Deteriorated Column / Beam Connection

Application of CFRP fiber sheet on a beam (wet lay-up process)

Application:
- monitoring of the load transmission
- monitoring of over load events (e.g. heavy load, earthquake)

Reference: Prof. Kachlakev, CalPolyCalifornia Polytechnic State University, San Luis Obispo
Strain Gage for Structural Integration

Cooperation with SALOMON

Application of the strain gages & production in series process

Aim: Measurement during skiing
Strain Gage for Structural Integration

<table>
<thead>
<tr>
<th>Load Situation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong></td>
<td>Bending loading and unloading</td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>High strain level in longitudinal direction, low</td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>Strain gauge configuration 3-1-5-9-7-3-5-1</td>
</tr>
<tr>
<td><strong>IV</strong></td>
<td>Strain gauge configuration 3-1-5-9-7-3-5-1</td>
</tr>
</tbody>
</table>

Control of the function of the strain gauges:

- **I**: MP 1.1 / 0°
- **II**: MP 1.2 / 90°
- **III**: MP 1.3 / 45°
- **IV**: MP 2.1 / 0°
- **V**: MP 2.2 / 90°
- **VI**: MP 2.3 / 45°
- **VII**: MP 3.1 / 0°
- **VIII**: MP 3.2 / 90°
- **IX**: MP 3.3 / 45°
- **X**: MP 4.1 / 0°
- **XI**: MP 4.2 / 90°
- **XII**: MP 4.3 / 45°
Strain Gage for Structural Integration

Laminated glass ...

... is a “composite”

different layers of glass and plastic (e.g. PVB, SGP)

Application:

- Load monitoring on architectural structures (snow & wind loads)
- Process control (residual stress)
Strain Gage for Structural Integration

Application of SG on human bones

Test on composite bones

Application: “Intelligent” bones with embedded SG
Booklet: “Integration of Strain Gages”

Content:
1. Fiber Composite Materials (6)
2. Composite Material Theory (6)
3. Basic Laminat Calculation (6)
4. Integration of SG (28)

Publication:
- free online version
LI66-10/350
Strain gages (SG) for integration in fiber composite materials

Special features
- Laminates of glass fibers
- Quality of strain gauges
- Total quality of production
- Precise--measuring points
- Mechanical properties of laminae
- Strain gauges and composite materials
- Shop for products and services
- Data Sheet

Specifications

<table>
<thead>
<tr>
<th>Spec.</th>
<th>Value</th>
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<tbody>
<tr>
<td>Nominal resistance</td>
<td>350 Ω</td>
</tr>
<tr>
<td>Nominal tolerance</td>
<td>±0.35</td>
</tr>
<tr>
<td>Temperature coefficient of the gauge factor</td>
<td>1 ppm/°C</td>
</tr>
<tr>
<td>Temperature range for composite materials</td>
<td>-60°...180°C</td>
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<td>Temperature range for composite materials</td>
<td>±3 ppm/°C</td>
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</table>
thank you...

...for your attention