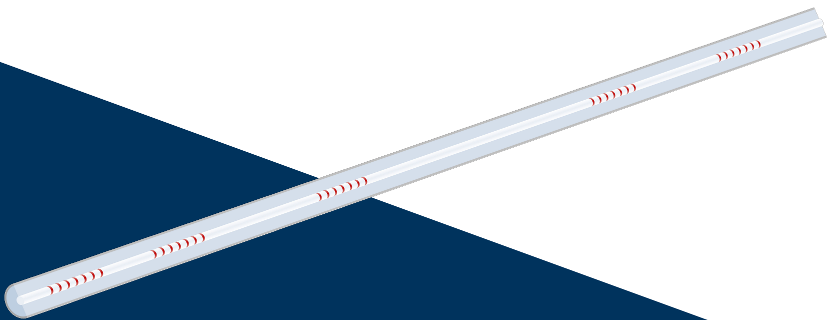
ENGLISH

Mounting Instructions



FS70FBG

Array of bare FBG

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1 GENERAL INFORMATION

The following instructions refer to the installation procedure of the FS70FBG Array of bare FBGs.

Material Numbers
K-FS70FBG

2 SENSOR INSTALLATION

The following instructions show guidelines for the installation of the FS70FBG Array of Bare FBG on smooth surfaces for measuring strain.
For embedding in composite materials or applying in non-uniform surfaces (where strain gradients over the FBG length occur), please contact HBK FiberSensing.

2.1 List of materials

Included material
FS70FBG Array of FBG

Needed material
Sanding sheets.
Surface cleaning agents. Recommended HBK: 1-RMS1 or 1-RMS1-SPRAY
Tissues. Recommended HBK: 1-8402.0026
Drafting tape. Recommended HBK: 1-KLEBEBAND
Glue. Recommended HBK: 1-EP310S, 1-X60 Recommended Third Party: DP490 from 3M
Protection. Recommended HBK: 1-ABM75 and/or 1-AK22

2.2 Preparation of the installation area

The surface of the material to instrument needs to be cleaned ensuring that no dust nor grease is present in gluing area.

Clean the surface using RMS1 cleaner (*Fig. 2.1*) and the non-woven tissues (*Fig. 2.2*), as recommended.

Fig. 2.1 Spraying 1-RMS on specimen

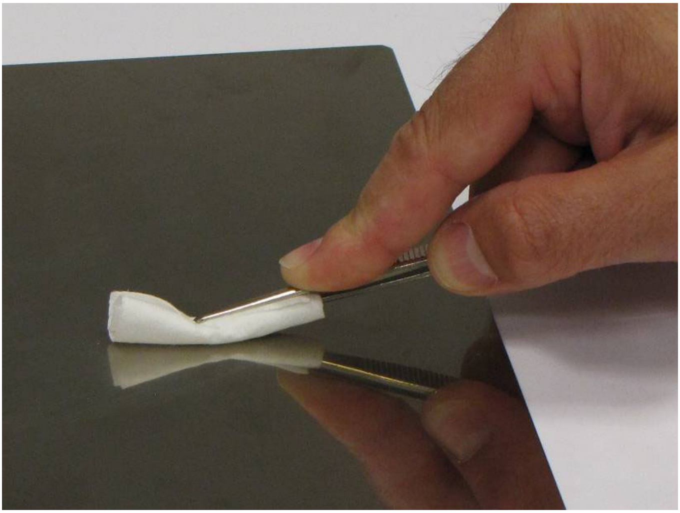

Fig. 2.2 Cleaning with nonwoven pad

The wiping movements should always be performed in the same direction until the last tissue comes out clean.

For installation with EP310S adhesive, the surface of the measuring point must be roughened using 220 grain emery cloth or finer emery cloth worked in circles (*Fig. 2.3*)

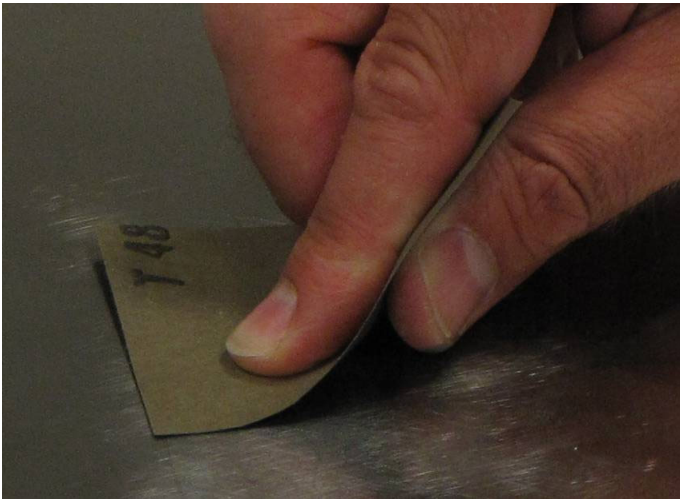

Fig. 2.3 Roughening the surface using emery cloth

Clean the roughened installation surface again with RMS1 and non-woven pads (*Fig. 2.4*)

Fig. 2.4 Cleaning the roughened installation surface

2.3 Marking the measuring point

Define the alignment of each FBG considering the measurement direction. The FBG is centered at the midpoint between the marking lines.

This step is particularly important as the fiber positioning dictates the measurement direction.

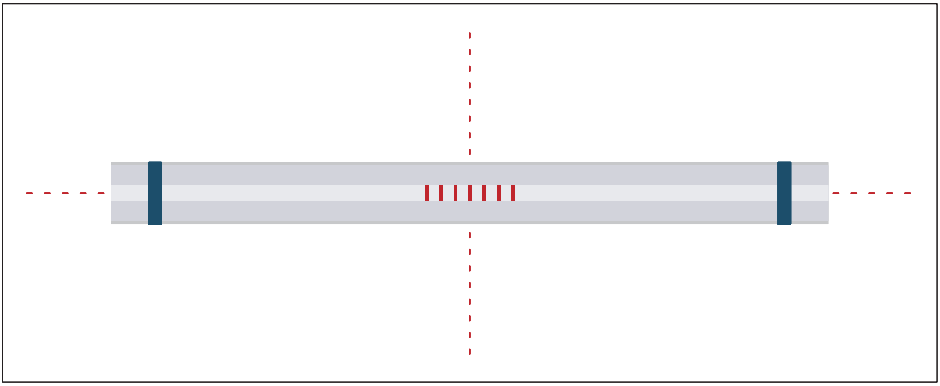

Fig. 2.5 FBG alignment markings

In the ideal case, an empty ball point pen cartridge is recommended for marking the installation point. The length of the marking line should be approx. 60 mm in the measurement direction. A vertical marking line, approx. 40 mm long, must be drawn starting at the center of the installation point, *see Fig. 2.6*.

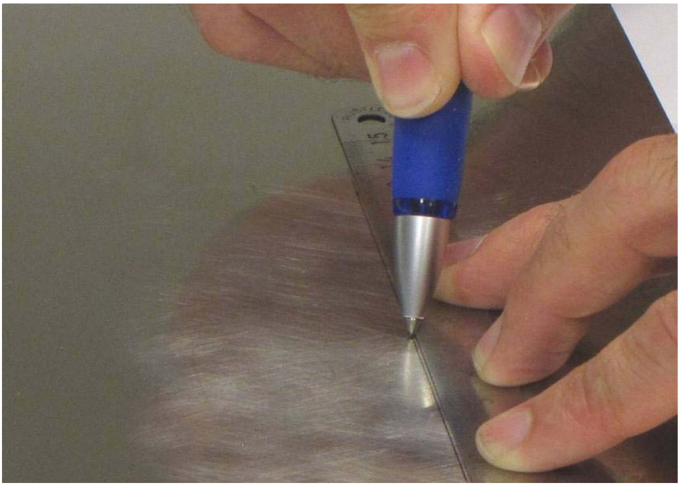

Fig. 2.6 Marking the marking lines

Once the area is marked out, the installation point must be cleaned very thoroughly, *see Fig. 2.7*. Please note that a new non-woven pad must be used each time the point is wiped. Repeat the cleaning process until no residues can be detected on the non-woven pad.

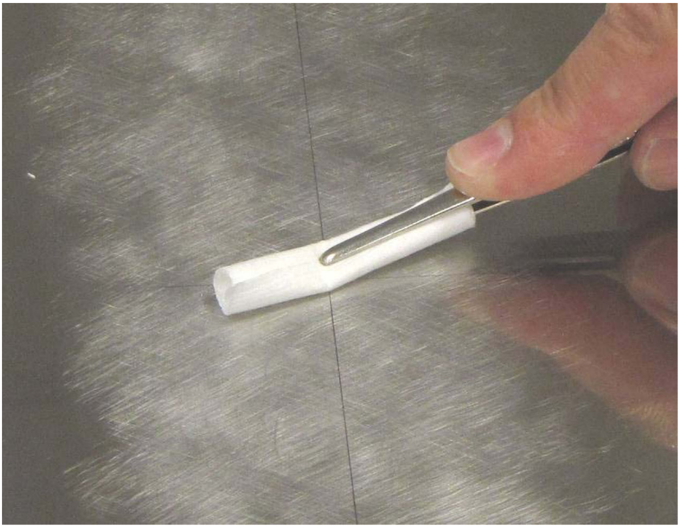

Fig. 2.7 Final cleaning of the installation point

Position the optical fiber with the FBG centered on the measuring point under small tension such that the fiber lies as straight as possible. Fix the fiber in this position with two polyimide adhesive stripes (order number 1-KLEBEBAND) outside the fiber markers (*Fig. 2.8*)

Fig. 2.8 Fixing the optical fiber

2.4 Gluing the sensor

The selection of adhesives and the gluing process determines the operation of the FS70FBG as a strain sensor in terms of measurement range and operating temperatures. Always refer to the installation instructions of the adhesive for details.

Important

Gluing process may lead to changes in the spectral response of the FBG, with impact on the quality of the measurement.

2.4.1 Using EP310 adhesive

EP310 bonding shows the optimal results with respect to creep at elevated temperature and elevated strain. EP310 is a hot curing adhesive. This means that it can be used only if heating can be easily applied to the measuring piece. The minimum temperature of curing EP310 is 80°C (with a curing time 8 h).

Apply EP310 adhesive (order number 1-EPS310) along the complete FBG bonding area. The bonding length should at least comprise the markers. Allow the adhesive to dry for 5 minutes at room temperature.

When bonding with EP310, it is important that the fiber directly touches the surface along the complete bonding length.

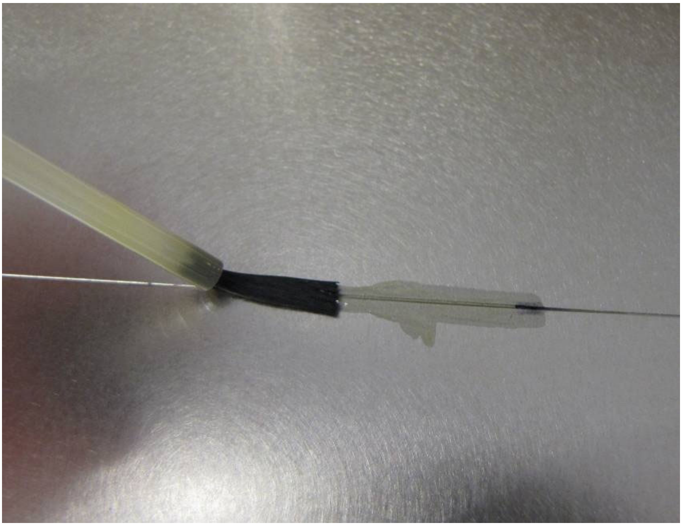

Fig. 2.9 Covering the FBG bonding area with EP310 adhesive

Place a piece of Teflon foil (order number 1-Teflon) and two stripes of silicone rubber (enclosed EP310) on top of the installation point. The silicone stripes should measure 2 cm x 4 cm.

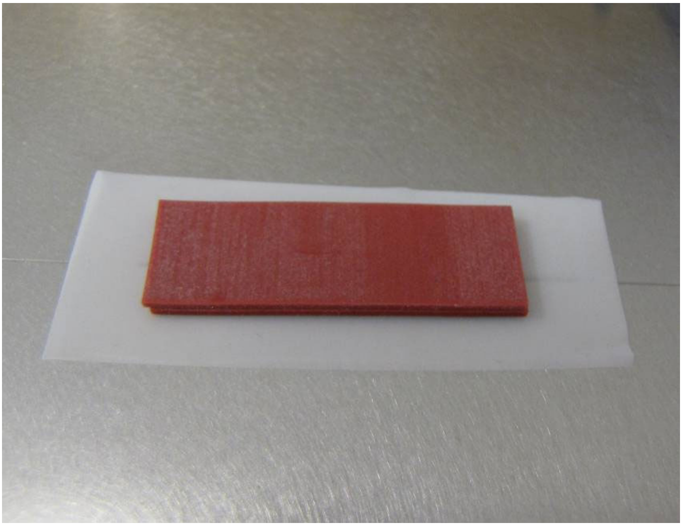

Fig. 2.10 Covering the optical fiber bonding area with Teflon foil and two stripes of silicone rubber

Put a flat load of 1 kg on top. The load should be mounted symmetrically on top of the FBG bonding area.

Fig. 2.11 Load on top of the optical fiber FBG bonding area

The EP310 adhesive must cure preferably for 2 h at 150ºC, or at 80 °C for at least 8 h.

2.4.2 Installation with epoxy adhesive

When using a two component epoxy (for example the suggested DP490 from 3M) the bonding length of the FBG must be surrounded by the glue. Bonding length must be at least between the two markings (50mm centered at the FBG).

- Start by creating a groove using two polyimide tape stripes (order number 1-KLEBE-BAND), long enough to fit the bonding area, placed in parallel and symmetrically to the fiber.

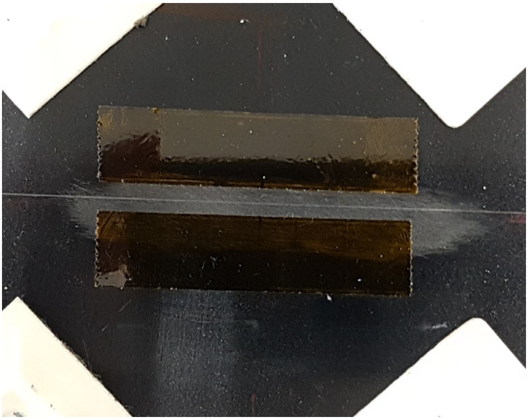

Fig. 2.12 Gluing groove.

- Apply a very thin cord of epoxy glue along the bonding length.

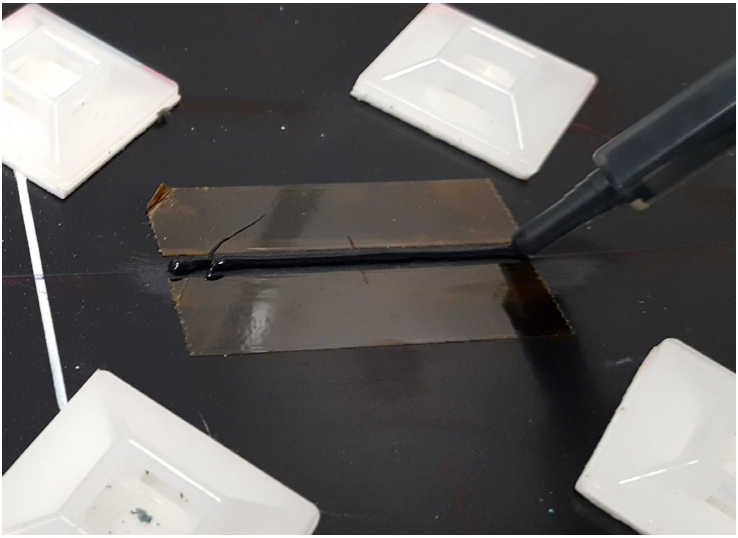

Fig. 2.13 Applying the epoxy glue.

- Very gently slightly twist the fiber from one side to the other, ending on the initial position. This will ensure that the fiber is fully involved in glue, while it is kept as close as possible to the surface.

Information

The position of the fiber, in the end, should remain in a straight line and aligned to the desired measuring direction.

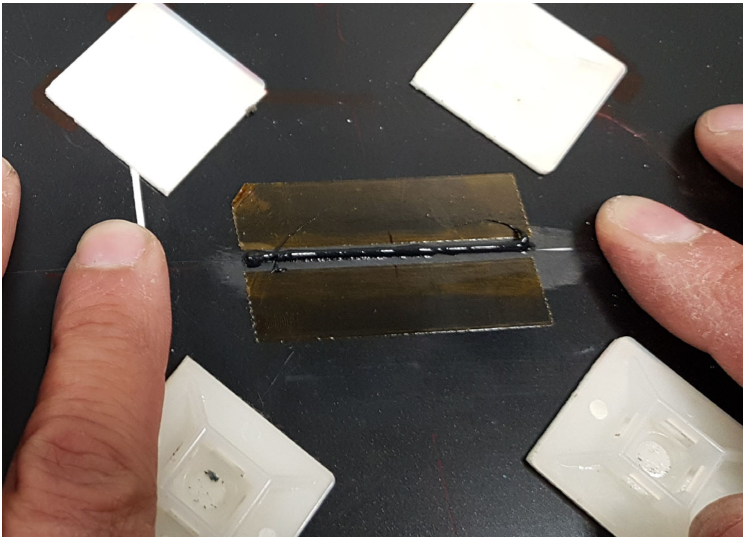

Fig. 2.14 Twisting the fiber.

- Using a non-metallic spatula or any similar flat tool, spread the glue along the groove making a continuous movement on a single direction. The movement should not be interrupted, meaning that it should start from one end until the other. This step will spread the glue over the full area of the groove and remove the excess of glue to the sides.

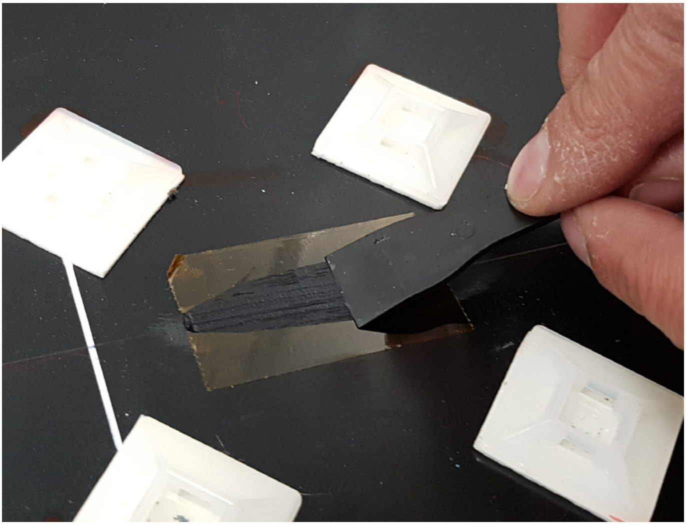

Fig. 2.15 Spreading the glue with a spatula.

▶ Apply a piece of polyimide tape on top of the FBG and the glue.

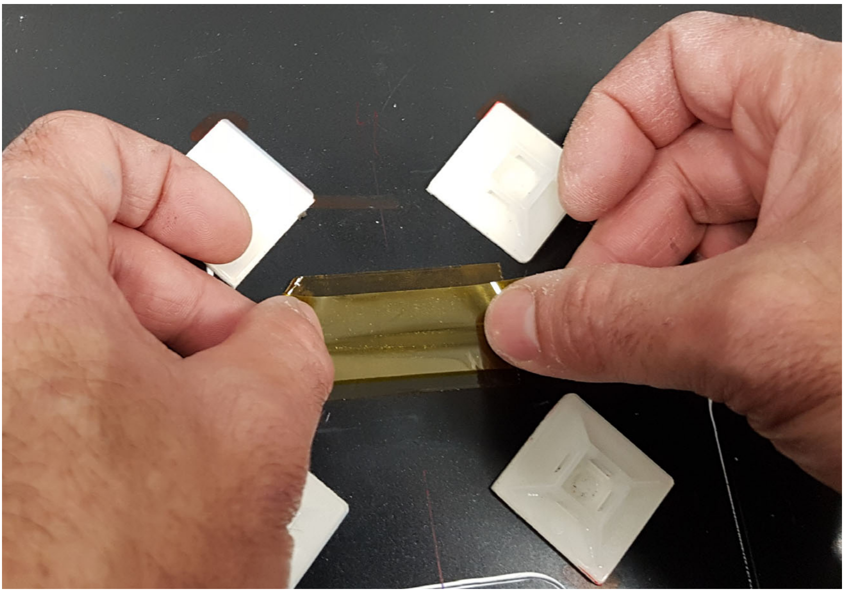

Fig. 2.16 Applying a new piece of polyimide tape.

- Repeat the process of spreading the glue with a spatula, this time over the polyimide tape.

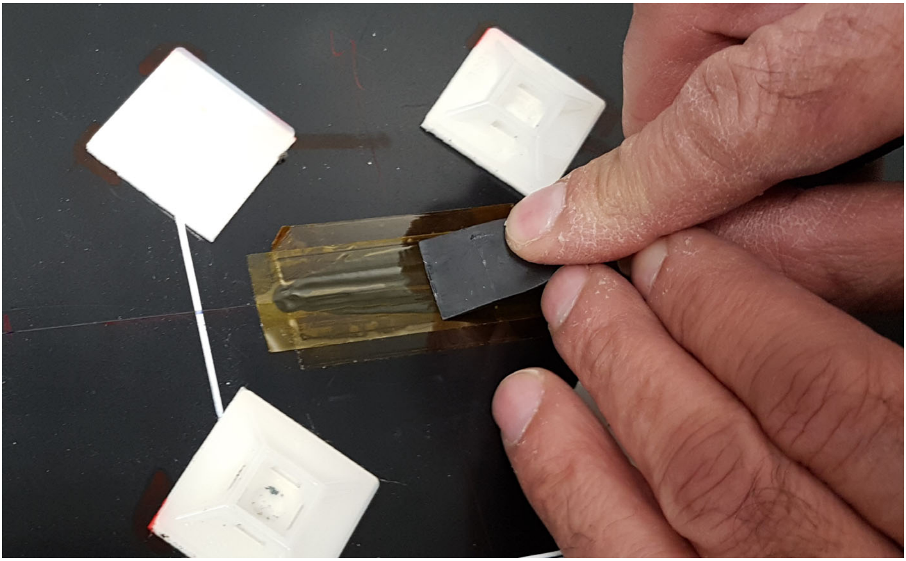

Fig. 2.17 Spreading the glue with a spatula.

- Reapply stress on the fiber, if needed adjusting the fixation tape.

Information

The position of the fiber, in the end, should remain in a straight line and aligned to the desired measuring direction.

▶ Place a piece of rubber on top of the gluing area and with the support of a stiff material apply continuous pressure.

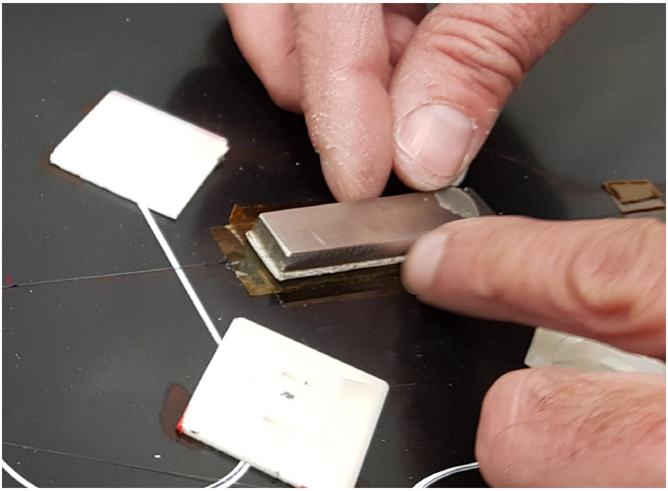

Fig. 2.18 Aligning the rubber and stiff auxiliary piece.

▶ Keep pressuring for 1 to 2 minutes.

Fig. 2.19 Applying uniform pressure over the FBG.

- After this, remove the auxiliary piece and the rubber and pull the fiber on both extremes to ensure the correct alignment of the FBG. Reapply the initially applied tapes to secure the fiber in this tensioned position.
- Repeat the steps of spreading the glue with a spatula and pressure again for 1 to 2 minutes using the layered rubber and block.
- Wait for a total hardening of the epoxy glue and remove the polyimide tapes used during the gluing process.

Information

At room temperature the suggested DP490 glue needs 24 h to cure. For other curing temperatures please refer to the supplier instructions.

2.5 Protecting the fiber path

In between FBG or between the FBG and the transition to the cable, it might be important to protect the fiber path. The need and exact solution will mostly depend on the application and on the environmental conditions.

2.5.1 Using epoxy adhesive

One possibility for protecting the fiber is using the suggested DP490 glue. The following suggests the use of a foam tape which provides a better-looking finishing.

- Create a grove around the fiber path using foam tape with approx. 1 mm thickness (recommended TESA Powerbond).

Fig. 2.20 Groove along the fiber using foam tape (optional).

- Apply the epoxy glue along the path.

- Use a spatula to smoothen the glue surface and fill the full width of the groove by gently pressuring it against the foam tape making a continuous movement on a single direction.

Fig. 2.21 Spreading the glue with a spatula.

Wait for approx. 2 hours.

- Remove the red protection film of the tapes (optional). This will ensure a better-looking finish.

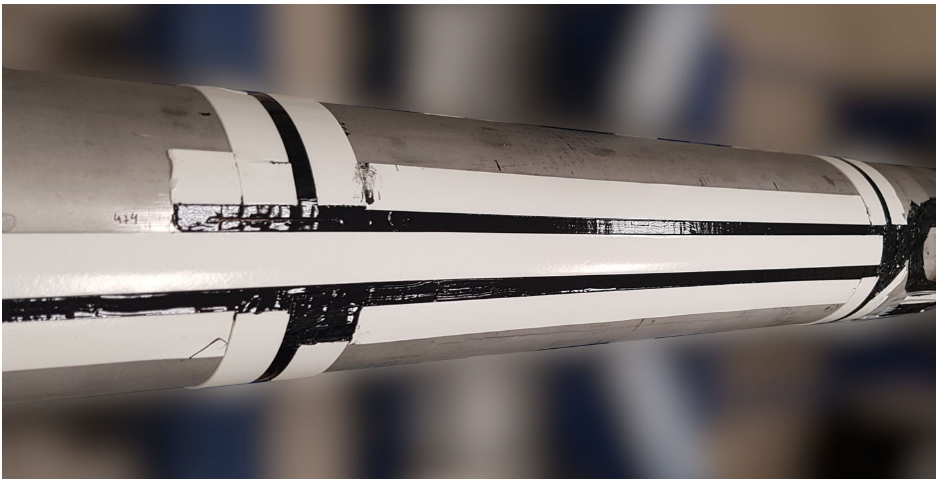

Fig. 2.22 Removing the red protection film.

Wait for the glue to harden.

- Remove the tapes.

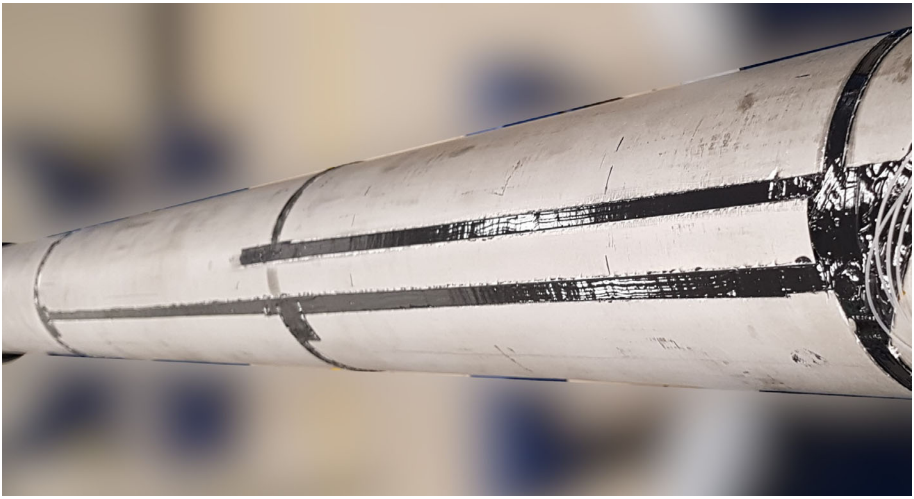

Fig. 2.23 Finished protection.

2.6 Routing and protecting the cables

FS70FBG sensor can be delivered with or without cable, and with different types of cables.

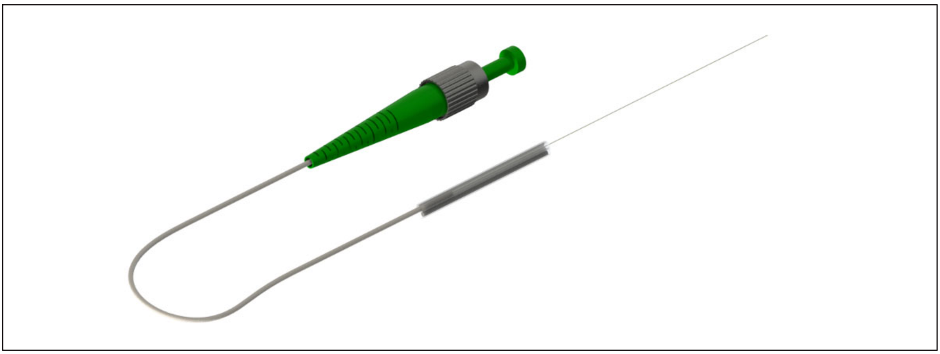

Fig. 2.24 Braided cable termination

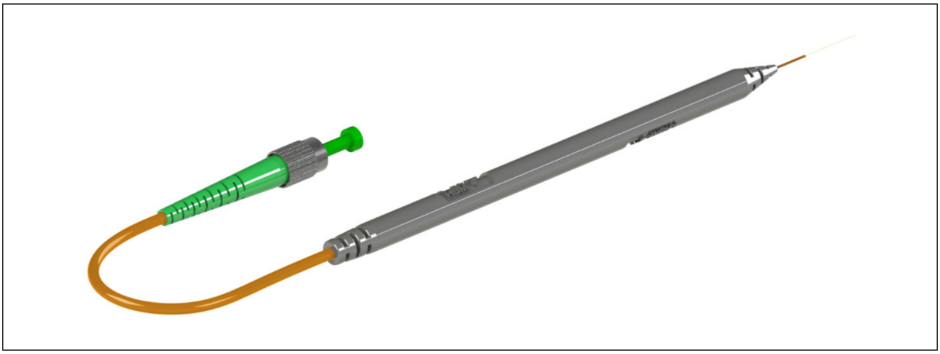

Fig. 2.25 Aramid cable termination

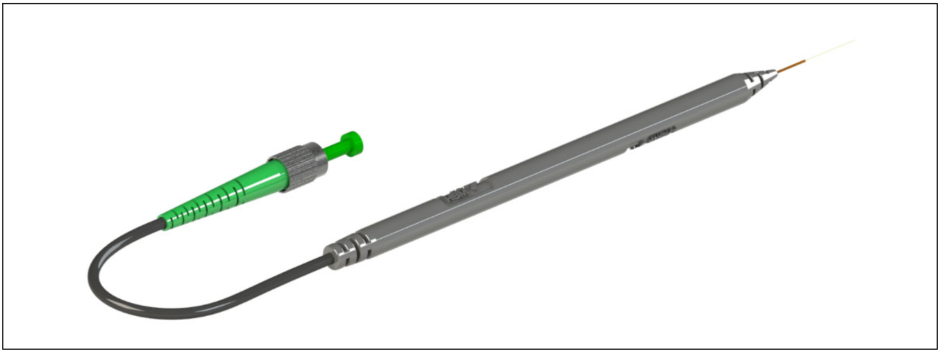

Fig. 2.26 Armor cable termination

Sensor cable should be routed ensuring that cables are not hanging and curvatures are kept within the limits for the used cable. The cable should be fixed by means of clamps or strong tape. Splice protections must also be well fixed. The splice interface on the FS70FBG is a fragile location due to the difference of rigidities. This is especially true when considering the 3mm cables (aramid or armor).

3 SENSOR CONFIGURATION

3.1 Strain

Strain sensors are not calibrated sensors. The characteristic sheet delivered with the sensor presents the sensor data for correct strain computation.

For the fiber Bragg grating strain sensors, wavelength variation including the effect of temperature is given by the equation as shown in *Fig. 3.1*.

$$\frac{(\lambda - \lambda_0)}{\lambda_0} = k \cdot \left(\varepsilon_{Load} + (TCS + CTE) \cdot (T - T_0)\right) \cdot 10^{-6}$$

Fig. 3.1 Wavelength variation of a strain FBG due to strain and temperature effects

Where

- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- *k* is the strain k factor of the strain sensor, dimensionless
- ε_{Load} is the mechanical strain applied to the structure in µm/m
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/°C
- *CTE* is the thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/°C
- T-T_0 is the temperature variation since the reference instant to the measurement instant in °C

Measurement with no compensation

If no temperature compensation is required the strain computation can be done as shown in *Fig. 3.2*.

$$\varepsilon = \frac{(\lambda - \lambda_0)}{k \cdot \lambda_0} \cdot 10^6$$

Fig. 3.2 Strain without temperature compensation computation formula

Where

- ε is the measured strain in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- *k* is the strain k factor of the strain sensor, dimensionless

Measurement with temperature compensation using a temperature sensor

Calculating compensated strain, in µm/m, using a temperature sensor is straightforward as the output of a temperature sensor is a temperature value in °C. The calculation is the depicted in *Fig. 3.3*.

$$\varepsilon_{Load} = \frac{(\lambda - \lambda_0)}{k \cdot \lambda_0} \cdot 10^6 - (TCS + CTE)(T - T_0)$$

Fig. 3.3 Strain computation with temperature compensation using a temperature sensor

Where

- ε_{Load} is the mechanical strain applied to the structure in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/°C
- *CTE* is the thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/°C
- T is the measured temperature of the used temperature sensor in °C
- T_0 is the temperature from the temperature sensor at the reference instant in °C

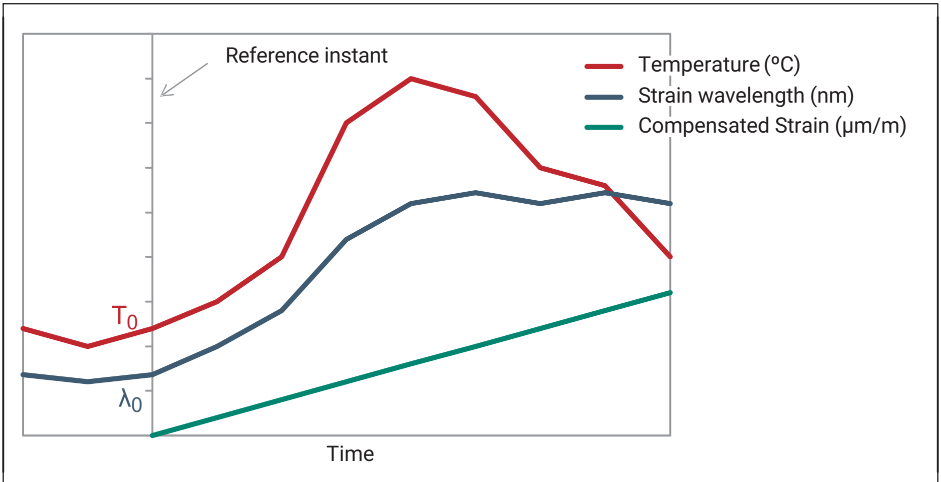

Fig. 3.4 Reference instant for temperature compensated strain measurement when using a temperature sensor for compensation

Measurement with temperature compensation using a compensation element

Strain measurement can also be correctly compensated using a compensation element based on FBG technology. Different approaches can be used:

- a temperature sensor without calibration certificate
- a strain sensor installed on a strain-free area of the same material
- a strain sensor installed on a strain-free material with a known CTE

The computation of strain can then be performed using the equation from *Fig. 3.5*.

$$\varepsilon_{Load} = \frac{\lambda - \lambda_0}{k \cdot \lambda_0} \cdot 10^6 - \frac{\lambda_{Tc} - \lambda_{0_{Tc}}}{\lambda_{0_{Tc}}} \frac{(TCS + CTE)}{TCF}$$

Fig. 3.5 *Strain computation with temperature compensation using an FBG compensation element*

Where

- ε_{Load} is the mechanical strain applied to the structure in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- λ_{TC} is the measured Bragg wavelength of the compensation element in nm
- $\lambda_{0\,TC}$ is the Bragg wavelength of the compensation element at the reference instant in nm
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/°C
- *CTE* is the thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/°C
- *TCF* is the temperature compensation factor of the compensation element in (µm/m)/°C. For an uncalibrated temperature sensor the value is given on the sensor's characteristics sheet. For a strain sensor attached to a specific material TCF can be calculated as shown in *Fig. 3.6*.

$$TCF = (5.7 + k \cdot CTE_{TC})$$

Fig. 3.6 *Temperature compensation factor computation*

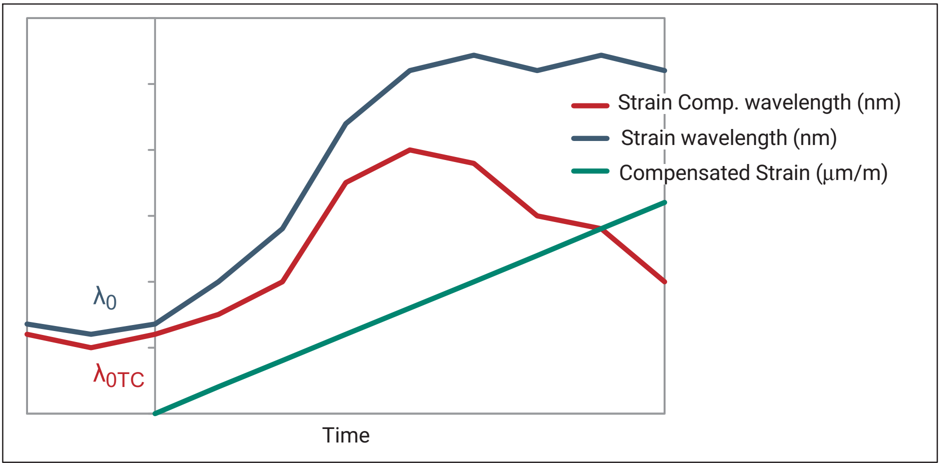

Fig. 3.7 Reference instant for temperature compensated strain measurement when using an FBG compensation element

Measurement with bending moment correction

When measuring on an element using a sensor that is far away from the attachment surface there may be an “error” on the measurement because the distance between the measuring point/alignment and the neutral axis is different to the distance between the installation surface and the neutral axis.

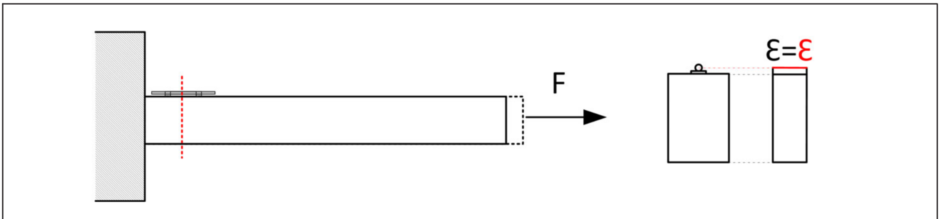

Fig. 3.8 Strain on pure axial deformation

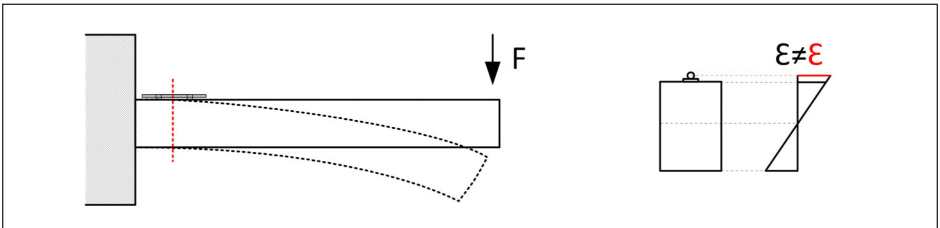

Fig. 3.9 Strain on pure bending moment

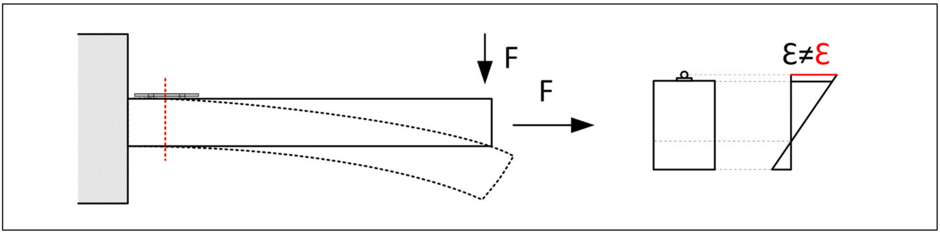

Fig. 3.10 Strain on axial load and bending moment

This becomes of high importance when the distance between the sensing element on the sensor to the attachment surface is relevant, or the measuring object is very thin. This distance on the FS70FBG Bare Fiber Bragg Grating is 0.095 mm (h_2 on *Fig. 3.11*).

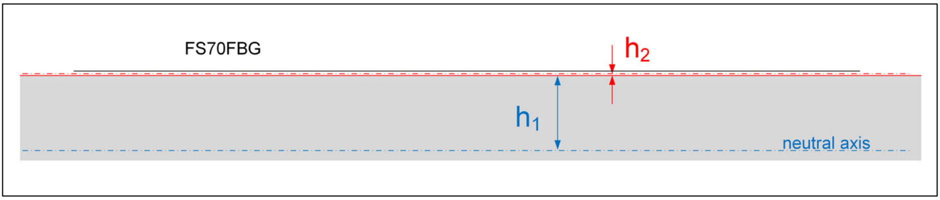

Fig. 3.11 Distance of the FBG to the mounting surface on the FS70FBG

However, knowing the distance to the neutral axis (h_1) the measured strain from the sensor can be corrected into strain on the surface by a geometrical factor:

$$\varepsilon_{surface} = \frac{\lambda - \lambda_0}{k \cdot \lambda} \cdot \frac{h_1}{h_2 + h_1} \cdot 10^6$$

Fig. 3.12 Strain computation bending effect correction

Where

- $\varepsilon_{surface}$ is the mechanical strain on the measuring surface in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- h_1 is the distance from the measuring surface to the neutral axis in mm
- h_2 is the distance from the measuring surface to the FBG in mm (0.095 mm for the FS70FBG)

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