MANUFACTURING OF STRAIN GAUGES & TRANSDUCERS
Tr. Tomase Bati 5146, CZ-760 01 Zlin, Czech Republic
Phone: +420 577 217 171 Fax: +420 577 217 172 E-mail: info@vtsz.cz

THE BONDING OF SILICON RESISTANCE STRAIN GAUGES AND CONNECTING THEIR TERMINALS TO MEASUREMENT CHAINS

1. General Information

1.1 Chemical hardening adhesives have significantly more favorable properties for attaching the resistance strain gauge to the object subject to measurement, than physical hardening adhesives by solvent evaporation. Strain gauge adhesives shall particularly be highly resistant to creep. The required properties are provided by adhesives based on the following:

- epoxide hardening at temperatures exceeding 100°C
- cyanoacrylate hardening at room temperature due to the influence of air humidity
- polyamide hardening at higher temperatures enabling the measurement from cryogenic temperatures up to 400°C, though more expensive and their availability is poor

See chapter 5.3., par. a) for an overview of adhesives applied most as well as their basic characteristics.

1.2 The basic criterion of quality of the strain gauge adhesive is glide caused by creep, expressed by a percentage change of the strain gauge signal at constant proportionate deformation, usually 1×10^{-3} and a constant temperature, most frequently after 30 minutes or by the graph expressing the time dependency of this change.

$$d_t = \frac{R_{e.1} - R_{e.2}}{R_{e.1}} \times 100$$

where d_t glide of the deformed strain gauge over time t [%]
$R_{e.1}$ resistance of the strain gauge to the deformation moment [Ω]
$R_{e.2}$ resistance of the strain gauge after time t from deformation has lapsed [Ω]

1.3 The ashesive selection is determined by the required measurement accuracy and conditions. Sensors and static strain gauge measurements require the glide at a room temperature in hundredths of %. Dynamic measurements are less demanding for glide values. Only several types of numerous industrially used epoxides and cyanoacrylates available provide acceptable glide.

1.4 The strain gauge adhesive can be obtained either from foreign suppliers of strain gauges or directly from adhesive manufacturers. With adhesive supplied by the manufacturer, it is always necessary to verify whether it has a satisfactory glide, performed with every delivery.

1.5 A high deformation sensitivity of silicon strain gauges enables determining the efficiency of the deformation transfer, for strain gauge adhesives, from the measured object to a strain gauge. It is directly proportional to the values of constants in the deformation equation of strain gauge C_1 and C_2. Therefore, for accurate measurements, the correction factors of constants C_1 and C_2 for the selected adhesive are introduced.

$$k_{c1} = \frac{C_{1M}}{C_{1Z}} \qquad k_{c1} = \frac{C_{2M}}{C_{2Z}}$$

where.................. k_{c1}, k_{c2}.......... correction factor for the multiplying of values for deformation equation constants C_1, C_2 mentioned in the attest, detected with a strain gauge attached using cyanoacrylate adhesive for accurate measurements
C_{1M}, C_{2M} ... values of constants C_1, C_2 detected with a strain gauge attached using the selected epoxide
C_{1Z}, C_{2Z}..... values of constants C_1, C_2, detected during the "strength" test of the strain gauge attached using cyanoacrylate

Additional data:

a) Every silicon strain gauge shall be subject to a test of tension and pressure deformation $\pm 2.5\times 10^{-3}$, to eliminate silicon active components with monocrystalline structure defects otherwise undetectable.

b) During deformation tests, strain gauges are attached to a test beam with cyanoacrylate adhesive. Resistance is measured on levels by 5×10^{-4}, during the application of load and relief, and this dependence of resistance on deformation is quantified by the constants of the deformation equation C_1 and C_2.

c) Cyanoacrylate adhesives are suitable for this test, for they can be easily removed from strain gauges by means of N,N-dimethylformamide or acetone, unlike epoxide adhesives.

d) For measurements with strain gauges attached using epoxide adhesives, the average values of correction factors are k_{c1}=1.05, k_{c2}=1.50

2. Surface Treatment of the Measured Object Before Applying Adhesive

2.1 The surface shall be free of dirt and paint coatings.

2.2 Grease from metal surface shall be removed using petrol, toluene, acetone or ethyl acetate by means of cotton wool or pulp balls. Always clean a larger area around the area where the strain gauge is attached, then it shall be wiped away from the centre to the edge using clean cotton balls and shall be increasingly reduced.

Additional iniformation:

a) Chlorinated hydrocarbons, for example trichloroethylene ($CHCl.CCl_2$), tetrachloromethane (CCl_4), which apart from unfavourable effects on the environment, release trace quantities of acidic substances with corrosive effects upon coming into contact with metals and with the effect of light, and can only be removed with difficulties, are not suitable for degreasing.

b) Unless sufficiently clean solvents supplied particularly for this purpose are available, whether they evaporate without residue shall be determined. Solvent shall be applied to the thoroughly cleaned area on which a continuous water film could be made before. After its evaporation, the water film should be applied on the area again. If water is dropping during this process, the solvent should be distilled

c) Cotton balls should never be soaked in the solvent in the storage vessel, but solvent shall always be poured into a bowl and after cleaning is completed, it shall not be returned back to the storage vessel.

d) Every ball shall be soaked in the bowl only once.

2.3 Immediately before attaching the strain gauge, the area shall be reground using emery cloth with a granularity of 180 to 240. Dust from grinding shall be perfectly removed using any solvent. The clean part of a cotton ball shall be used to wipe the area just once and the wiping process shall be repeated until traces of dirt are obvious on the cotton ball.

Additional information:

a) The area can be cleaned and roughed also by blast cleaning.

b) Fibres stuck on the cleaned area shall be wiped using dry cotton. Fingers shall never be used to remove them, nor shall we blow them with our mouths.

2.4 The cleanness of the surface before applying adhesive shall be checked by spraying distilled water. The water film stays on a well cleaned surface, dried with a cotton ball or pulp.

Additional information:

a) Suppliers of strain gauge adhesives also supply preparations for surface cleaning

b) The surfaces of some metal materials, for example titanium and its alloys, can sometimes be treated only with difficulties in order to be able to preserve a continuous water film. In general, adhesive joints on titanium have low strength and the only reliable manner of increase is the etching of areas before applying adhesive, for example using the following solution:

15 volume % of concentrated nitric acid
3 volume % of concentrated hydrofluoric acid
82 volume % of distilled water

The solution shall be applied to the determined area using a polyethylene tube, pulled out into the capillary, in the quantity, which does not spill beyond the specified area. It shall be drained with a cotton ball approximately 10 seconds after the effect, and the procedure shall be repeated. After sufficient etching, changing the metal appearance of the area into matte, it is washed with distilled water and neutralized with an approx. 3% water solution of ammonia (ammonia-NH_4OH) using a dropper and washed with distilled water.

c) The surface of structural steel can be etched before attaching strain gauges with a 3% solution of nitric acid (HNO_3) in alcohol (ethyalcohol-C_2H_5OH) using a dropper, then it can be washed with water, neutralized with an approx. 3% water solution of ammonia (NH_4OH) using another dropper and washed with alcohol.

d) The adhesive shall be applied to the treated metal areas as soon as possible.

e) Surfaces of non-metal materials shall be treated using methods common for the applicationof adhesive for these materials, described in the literature.

3. Silicon Resistance Strain Gauges

Work with silicon strain gauges shall be significantly facilitated with a binocular microscope, providing 5-10x zoom.

3.1 The silicon active part of the strain gauge without support is sufficiently solid and does not require load-bearing support. Steel tweezers with plain points are suitable for their handling. **Tweezers can only be used for handling the metal terminals of the strain gauge.**

Neither tweezers, nor other hard objects shall ever touch the silicon active part, for the slightest low-intensity pressure caused by a hard object can violate its surface structure, visually undetectable and accompanied with the significant decrease of its critical tensile strain to the values of approx. one per mille.

3.2 The surface of the silicon active part shall not be cleaned or anyhow treated. It has been treated in production plant so that strain gauge adhesives can show high adhesion.

4. Attaching Silicon Strain Gauges Without Support to the Measured Objects

4.1 The strain gauge has to be electrically insulated from the measured object. When attaching strain gauges without load-bearing support to the objects from electrically conductive materials, an electrically insulating subbase layer must be made in the area of the strain gauge attachment. Strain gauges can be attached directly to electrically non-conductive materials.

4.2 During the adhesive hardening process, the strain gauge shall be pressed to the measured object. The smaller area of the active part of the silicon strain gauge requires a lower compressive load than with the foil strain gauge. Preparations compressing strain gauges using stick-on weight allow a more accurate setting of compressive force than preparations using pressure springs. The dimension of the stick-on weight shall be selected within the range of 0.25 kg/cm^2 to 0.50 kg/cm^2. An abnormally high compressive load shall deform the silicon rubber splice plate positioned on the strain gauge in such significant extent that it can "cut out" a gold terminal with a diameter of 0.07mm at the joint with silicon.

4.3 Epoxide adhesives

They are used in sensors of mechanical values due to their low glide amounting to hundredths to low tenths of %. They enable strain gauge measurements within the range of –269°C to 300°C, for short-term periods also up to temperature of 400°C. They mostly harden at higher temperatures. If the resin component fails to react with the hardening component at storage temperatures, both components are supplied as mixed.

The subbase layer can be created on the object surface treated according to par. 2 and it shall be hardened according to the instructions of the adhesive supplier. The optimal thickness of the layer is 0.02mm - 0.03mm. The hardened subbase layer shall not be violated with unhardened adhesive. The adhesive application procedure is as follows:

- the adhesive layer without air pockets shall be applied to the bottom level of the silicon active part (using a wooden or plastic sticks) and solvent shall be left to evaporate from it
  The bottom area of the strain gauge is the one without terminals attached.
- the layer shall be strong enough so the strain gauge load can force out the adhesive next to the silicon active part, more diluted adhesives require application of several layers after solvent evaporation.

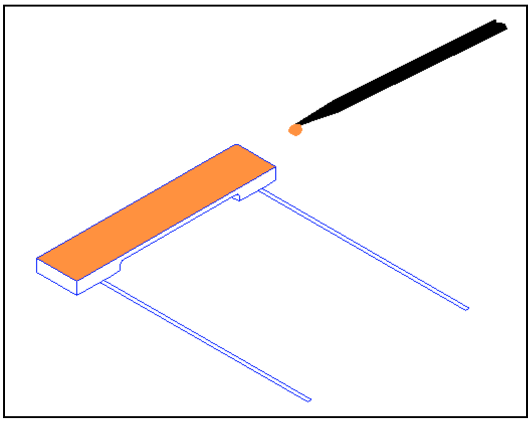

Figure 1

- the strain gauge shall be handled with tweezers using one of the terminals, it shall be reversed and the bottom area with the adhesive applied shall be placed to the subbase layer
- the strain gauge shall be accurately placed using terminals by means of tweezers

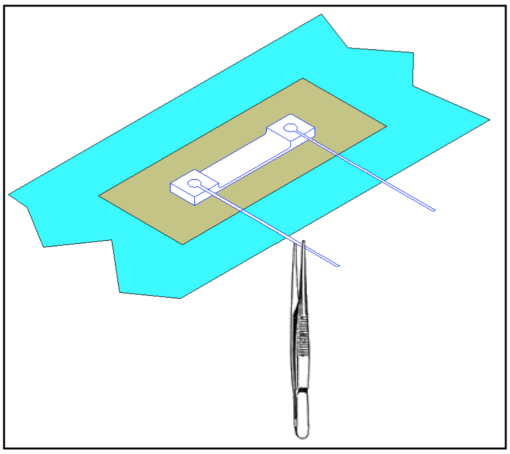

Figure 2

- terminals shall be fixed by sealing up with an adhesive tape resistant to hardening

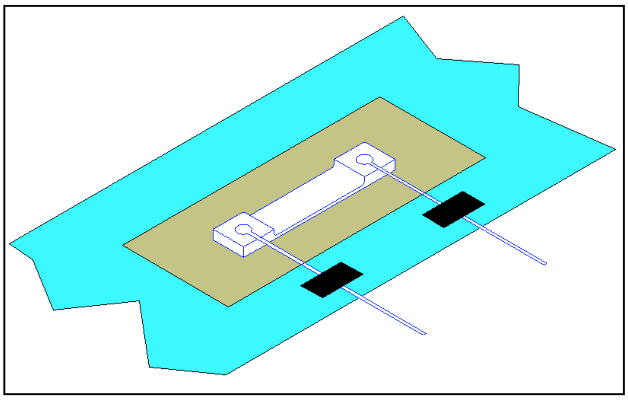

Figure 3

- a 0.7mm thick silicon rubber separation splice plate shall be placed on the strain gauge and on it a metal splice plate shall be placed or heat-resistant shaping substances whose shape is identical with the object surface

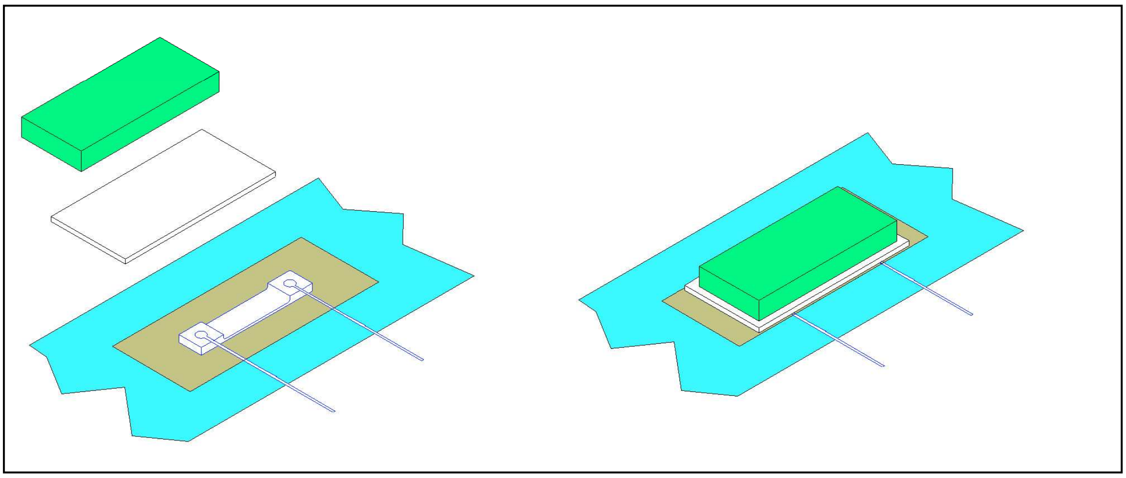

Figure 4

- load preparation shall be loaded with weight of 0.25 - 0.50kg per every cm^2 of the splice plate area

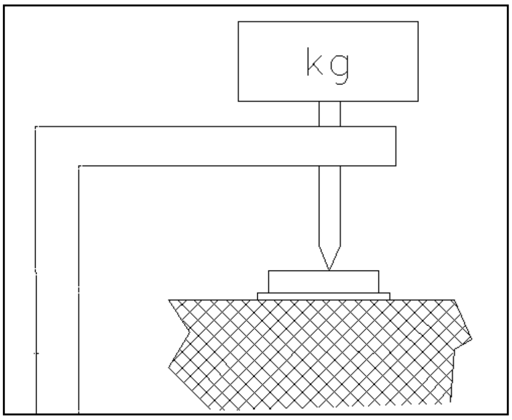

Figure 5

- load preparation with the measured object shall be transferred into the premises with the prescribed temperature and hardened during the prescribed period.

4.4 **Cyanoacrylate adhesives**

These adhesives harden at room temperature due to the influence of air humidity because of high reactivity with hydroxyl ions. Optimal hardening conditions require 60% to 80% of relative humidity and temperatures from +15ºC to +30ºC. The alkalinity of the object surfaces accelerates hardening, surface acidity decelerates or even disables hardening. They are used for common measurements. They are not suitable for sensors since their glide is on the level of tenth of %. Hardened cyanoacrylate layers dilute in fluid cyanoacrylate adhesives. Therefore on the measured object there is a 0.02mm thick subbase layer from glass cloth or cigarette paper, which shall be saturated with cyanoacrylate adhesive. Further steps as follows:

- the adhesive shall be applied with a sufficient layer to the bottom area of the strain gauge as is described with epoxide adhesives (see Figure 1) and the strain gauge shall be immediately attached since cyanoacrylate adhesives do not contain any solvents, or the adhesive shall be applied to the subbase layer created on the measured object
- after the adhesive application to the bottom area, the strain gauge shall be handled with tweezers by one of the terminals, reversed and the bottom area with the adhesive applied shall be placed to the subbase layer (see Figure 2)
- the strain gauge shall be accurately placed using terminals by means of tweezers
- the terminals shall be fixed by applying a narrow strip of self-adhesive tape (see Figure 3)
- a silicon rubber separation 0.7mm thick splice plate shall be placed on the strain gauge and on it, a metal splice plate shall be placed or shaping substances whose shape is identical with the object surface (see Figure 4)
- load preparation shall be loaded with weight of 0.25 - 0.50kg per every cm^2 of the splice plate area (see Figure 5)
- load preparation with the measured object shall be left in the premises with 60%-80% of relative humidity at temperature of +15°C-+30°C allowing adhesive hardening

The adhesive layer can achieve final hardness at room temperature in 20 hours or in 2 hours by heating at 70°C.
Measuring is possible after the adhesive layer hardens.

4.5 In cases calling for a load-bearing support for handling strain gauges, strain gauges can be attached to supports made from 0.02mm thick thin glass cloth or from a cigarette paper by applying the procedure above and attach it to the measured object after the adhesive hardens.

5. Attaching Silicon Strain Gauges With Support to Measured Objects

5.1 The surface of the measured object has to be treated before applying adhesive according to point 2.)
The electrical insulation of the strain gauge is secured by the support, hence the strain gauge with the support shall be attached straight to the measured object, i.e. without insulation layers.

5.2 During the adhesive hardening process, the strain gauge shall be pressed to the measured object. The smaller area of the active part of the silicon strain gauge requires a lower compressive load than with the foil strain gauge. Preparations compressing strain gauges using stick-on weight allow a more accurate setting of compressive force than preparations using pressure springs. The dimension of the stick-on weight shall be selected within the range of 2.7 kg/cm^2 to 3.5 kg/cm^2. An abnormally high compressive load shall deform the silicon rubber splice plate positioned on the strain gauge in such significant extent that it can "cut out" a gold terminal with a diameter of 0.07mm at the joint with silicon.

5.3 **Epoxide adhesives**

They are used in sensors of mechanical values due to their low glide amounting to hundredths to low tenths of %. They enable strain gauge measurements within the range of –269°C to 300°C, for

short-term periods also up to temperature of 400°C. They mostly harden at higher temperatures. If the resin component fails to react with the hardening component at storage temperatures, both components are supplied as mixed.
The subbase layer can be created on the object surface treated according to par. 2 and it shall be hardened according to the instructions of the adhesive supplier. The optimal thickness of the layer is 0.02mm - 0.03mm. The hardened subbase layer shall not be violated with unhardened adhesive.
The adhesive application procedure is as follows:

- the adhesive layer without air pockets shall be applied to the bottom level of the silicon active part (using a wooden or plastic sticks) and solvent shall be left to evaporate from it
<u>The bottom area of the strain gauge is the one without terminals attached.</u>

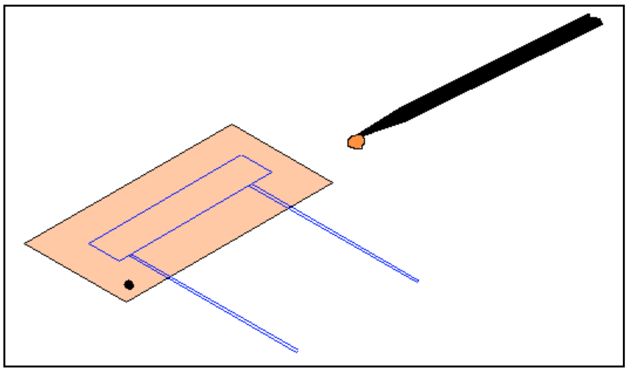

Figure 6

- the strain gauge shall be handled with tweezers using one of the terminals, it shall be reversed and the bottom area with the adhesive applied shall be placed to the subbase layer
- the strain gauge shall be accurately placed using terminals by means of tweezers

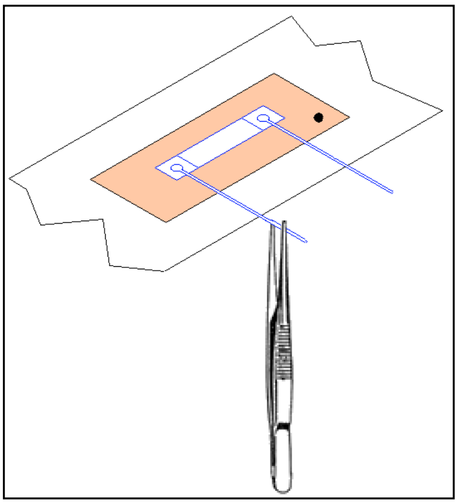

Figure 7

- terminals shall be fixed by sealing up with an adhesive tape resistant to hardening

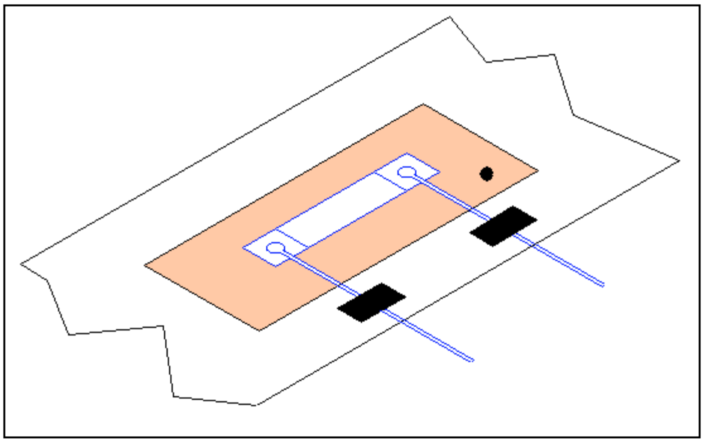

Figure 8

- a 0.7mm thick silicon rubber separation splice plate shall be placed on the strain gauge and on it a metal splice plate shall be placed or heat-resistant shaping substances whose shape is identical with the object surface (see Figure 4)
- load preparation shall be loaded with weight of 2.7 - 3.5kg per every cm^2 of the splice plate area (see Figure 5)
- load preparation with the measured object shall be transferred into the premises with the prescribed temperature and hardened during the prescribed period.

5.4 **Cyanoacrylate adhesives**

These adhesives harden at room temperature due to the influence of air humidity because of high reactivity with hydroxyl ions. Optimal hardening conditions require 60% to 80% of relative humidity and temperatures from +15°C to +30°C. The alkalinity of the object surfaces accelerates hardening, surface acidity decelerates or even disables hardening. They are used for common measurements. They are not suitable for sensors since their glide is on the level of tenth of %. Hardened cyanoacrylate layers dilute in fluid cyanoacrylate adhesives. Therefore on the measured object there is a 0.02mm thick subbase layer from glass cloth or cigarette paper, which shall be saturated with cyanoacrylate adhesive. Further steps as follows:

- the adhesive shall be applied with a sufficient layer to the bottom area of the strain gauge as is described with epoxide adhesives (see Figure 6) and the strain gauge shall be immediately attached since cyanoacrylate adhesives do not contain any solvents.
- after the adhesive application to the bottom area, the strain gauge shall be handled with tweezers by one of the terminals, reversed and the bottom area with the adhesive applied shall be placed to the subbase layer (see Figure 7)
- the strain gauge shall be accurately placed using terminals by means of tweezers
- the terminals shall be fixed by applying a narrow strip of self-adhesive tape (see Figure 8)
- a silicon rubber separation 0.7mm thick splice plate shall be placed on the strain gauge and on it, a metal splice plate shall be placed or shaping substances whose shape is identical with the object surface (see Figure 4)
- load preparation shall be loaded with weight of 2.7 - 3.5kg per every cm^2 of the splice plate area (see Figure 5)
- load preparation with the measured object shall be left in the premises with 60%-80% of relative humidity at temperature of +15°C-+30°C allowing adhesive hardening

The adhesive layer can achieve final hardness at room temperature in 20 hours or in 2 hours by heating at 70°C.
Measuring is possible after the adhesive layer hardens.

6. Attaching Tailor Made Strain Gauges and Strain Gauge Adhesives

6.1 The VTS company attach customer strain gauges to the objects supplied by customers. Strain gauge adhesives by Hottinger Baldwin Messtechnik or Vishay enabling measurements from -270°C to +300°C are applied.

6.2 If VTS company partners consider it purposeful to attach silicon strain gauges themselves, they can select between two options of obtaining the adhesive:

a) From foreign suppliers of strain gauges – basic information provided in the following tables:

Hottinger Baldwin Messtechnik GmbH

adhesive designation	type of adhesive	range of working temperatures			maximum storage period
		bottom	upper		
			statically	dynamically	
		°C	°C	°C	
Z 70	cyanoacrylate	-70	+100	+120	6 months
EP 250	epoxide	-269	+250	+315	6 months
EP 310	epoxide	-240	+260	+310	1 year

Vishay Measurements Group GmbH

adhesive designation	type of adhesive	range of working temperatures		maximum storage period
		short-term period	long-term period	
		°C	°C	
M-BOND 200	cyanoacrylate	- 185 – + 95	- 32 – + 65	6 months
M-BOND 43-B	epoxide	- 269 – + 175	- 269 – + 150	9 months
M-BOND 610	epoxide	- 269 – + 370	- 269 – + 260	9 months
M-BOND 450	epoxide	- 269 – + 400	- 269 – + 260	6 months

b) From adhesive manufacturers. First of all it is necessary to find the type among the offered adhesives with satisfactory properties of glide as well as additionally required properties. With each delivery, it is at least necessary to check the glide since these characteristics of adhesives have surprisingly wide tolerance.

7. Connection of Terminals of Strain Gauges To Measurement Chains

7.1 The terminals of silicon strain gauges with positive deformation sensitivity are made of alloy AuGa3 (gold with 3% gallium), strain gauge terminals with negative deformation sensitivity are made of alloy AuSb1 (gold with 1% antimony).

7.2 There are two most common methods of connecting the terminals to measurement chains:

- connecting terminals with soft solder on the terminal or directly to the copper wire, this method can usually bear temperatures from 110°C to 220°C for measurement according to the type of the applied solder
- by fusion point welding of the strain gauge terminal to the copper wire enabling measurement reaching the limit of heat resistance of strain gauges which is 370°C

7.3 Soldering of gold terminals requires adherence to general principles for soldering with soft solders (with fusion temperature lower than 450°C) and concurrent respecting of specific properties of the material pair:

- gold terminal of silicon strain gauge
- solder based on tin or lead.

The most important is the fast dilution of gold and its alloys in majority of soft solders. This can be solved in two ways:

a) To solder using common micro-solders and special solders diluting gold more slowly than ordinary tin solders.

b) To solder with ordinary micro-solders, to use ordinary soft solders and to eliminate unfavourable consequences of fast gold dilution in these solders by applying the appropriate working procedure.

The soldering procedure is as follows:

a) A thin film of fused solder is applied to the cleaned surface or terminal.

b) A drop of the fused solder shall be applied by means of the soldering point to the gold terminal connection.

c) The soldering point shall be taken away from the fused drop and at the same time the terminal of the strain gauge, which is held with tweezers, shall be inserted freely into it using your free hand. The gold terminal shall be inserted in the drop, applying an appropriate speed corresponding to the drop temperature, therefore the soldering point shall not be overheated.

d) After cooling the solder down, the quality of the terminal connection shall be checked. The correctly connected terminal goes out from the stiffened solder with an unweakened diameter. If the terminal is weakened in the place of the output from the solder, it shall be cut very close to the solder using a scalpel, a drop of the solder shall be repeatedly fused and the soldering process shall be repeated from point c).

7.4 The soldering agent of terminals shall always be non-etching soldering agent excluding the risk of joint corrosion.
The most suitable soldering agent for soldering of gold terminals with solders mentioned in the table is colophonium (mixture of hydroaromatic "rubber" abietic acids and together with isomer pimar adids – $C_{19}H_{29}COOH$), with efficient reaction temperature from 170°C to 270°C. The most frequently used agent is a 60% solution of colophonium in ethylalcohol (C_2H_5OH). The efficiency of this soldering agent can be increased significantly by adding 4% to 6% of hydrazine (NH_2NH_2).

7.5 In extreme measurement conditions, the terminals of strain gauges can also be connected to measurement chains by fusion welding of the gold terminal with copper wire. Gold and copper form a solid solution within the concentration ranges with the joint fusion temperature beginning at the temperature exceeding 850°C and for the given purpose the eventual origination of inter-metallic compounds is not critical (AuCu and $AuCu_3$).
One of the manners is welding using explosion from the battery of condensers for which capacity, voltage and discharge resistance can be set.

7.6 VTS Zlín supplies silicon strain gauges also with and without the support, with copper terminals equipped with a gold-plated or tin-plated layer preventing copper oxidation.

Fore information from the strain gauge manufacturer, contact us at **info@vtsz.cz** .