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Silicone encapsulation of the piezoresistive composite element as a low-cost packaging for measuring high-pressure

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Abstract

This paper presents various silicone encapsulations of the novel high-pressure composite element. Measurements at 100 MPa (1 000 bar or 14 500 psi) for different setups have been carried out successfully. The sensitivity of the softest truncated-cone-like encapsulated setup is nearly not reduced at 100 MPa, while the sensitivity of the harder encapsulations is reduced by 2% respectively 4% compared to the bare composite element.

Keywords: silicone, encapsulation, packaging, high-pressure, composite element

1. Motivation

The state-of-the-art packaging of conventional piezoresistive silicon pressure sensor dies is complex and usually costly. With increasingly numerous high-pressure applications, due to modern engineering, the requirements for the packaging and thus the costs also increase.

A low-cost packaging is the first step to protect the novel piezoresistive composite element already presented for measuring high-pressure (Fig. 1) [1].

With the novel operating mode of mechanical strain, based on hydrostatic pressurization, the overload protected design of the composite element – consisting of a compound of solid state silicon and mechanically mismatched counter body without a diaphragm [2,3] – it is possible to measure high-pressure of 500 MPa (equals 5 000 bar or about 72 500 psi) with a piezoresistive element.

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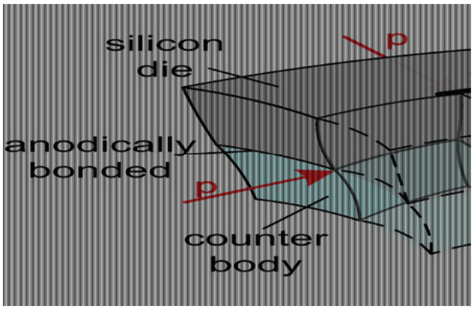

Fig. 1. Composite element; shell-shaped bent due to hydrostatic pressure load; 1.6 mm side length

Table 1. Naming of different setups with silicone casting

Setup name	Type 0	Type 1	Type 2	Type 3
Encapsulation	no	yes	yes	yes
Shore hardness of casting	-	A-25	A-45	A-49

2. Encapsulation

A silicone encapsulation as low-cost packaging is state-of-the-art for conventional silicon pressure sensors in the normal pressure range up to 1 MPa. For the composite element, a silicone casting for high-pressure applications is presented in this paper. To identify the influence of a silicone encapsulation on the pressure sensitivity, experimental setups with various flexible silicone casting compounds have been developed and built up. Four of these are discussed in this paper: one bare sensing element without casting as reference and three sensing elements encapsulated with silicones of varying hardness: Shore hardness A-25, A-45 and A-49. The naming of the different setups is shown in table 1. A casting mount is required to build up sensors with truncated-cone-like encapsulation (Fig. 2).

The optimization of the casting mount concerning mechanical stability and adhesion of the silicone casting compound is an angular (Fig. 3). Compared to a vertical limiter, there is the beneficial force distribution. The orthogonal component pushes the encapsulation against the casting mount, while the critical shear component is reduced. Thus, the mechanical stability of the casting compound is improved.

The four different setups according to table 1 were built up. Fig. 4 shows a photo of an encapsulated composite element of type 2 with the presented casting mount (Fig. 2 and 3). All three in this paper presented silicone casting compounds are transparent.

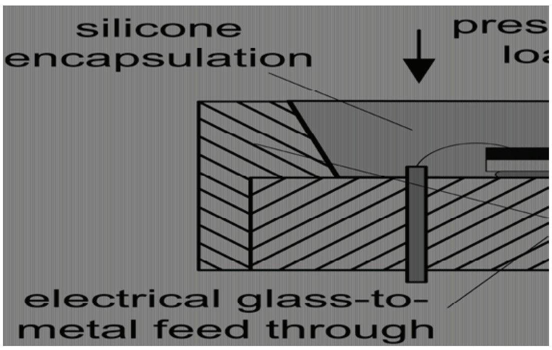

Fig. 2. Experimental setup of encapsulated composite element; the diameter of the casting mount is 15mm

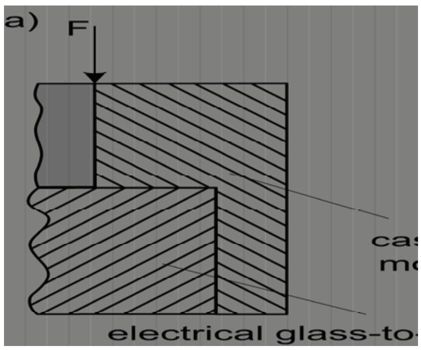

Fig. 3. Design of casting mount (left) without angle and (right) with angle

3. Measurement results

Initially, all measurements with the different castings have been performed with a nominal pressure of 100 MPa at room temperature of 23°C±1°C. The Wheatstone full bridge has been supplied with 2.5 VDC.

The load cycle shown in Fig. 5 is representative for several load cycles with reproducible values and has been performed for the different setups in such a way. This measurement was undertaken with an encapsulated composite element with the silicone casting compound of Shore hardness A-45 (type 2).

Due to the production tolerance of the composite element, there is an interval about the result of the measured nominal sensitivity. For the bare composite element the mean sensitivity is 57.5 µV/VMPa with a tolerance of ±0.5% as a result of several measurements at 100 MPa.

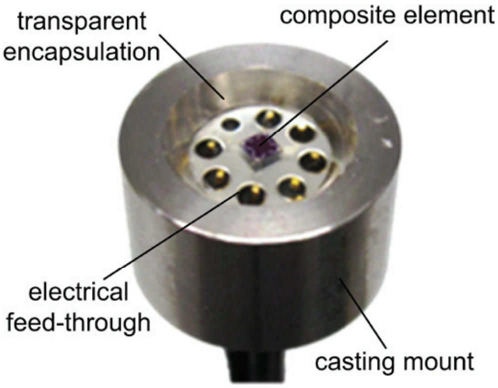

Fig. 4. Picture of the encapsulated composite element type 1 with the transparent silicone casting compound

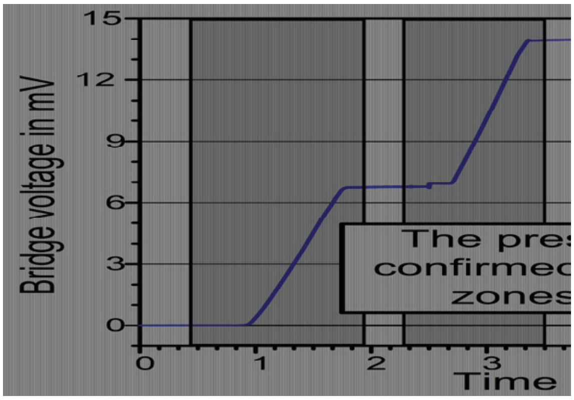

Fig. 5. Representative measurement of the encapsulated composite element (type 1); pressure range of 100 MPa; room temperature at 23°C ± 2°C; 2.5 V voltage supply

For comparison of the four setups, the calculated characteristic values are shown in table 2. The sensitivity-ratio shows the sensitivity of the setup relative to the mean sensitivity.

The setup type 0 without casting shows a sensitivity (table 2) smaller than the mean sensitivity, but within the tolerance range of ±0.5%. In comparison with type 1 with the softest casting compound, the measured sensitivity is higher than the mean one and that of the bare sensing element. But the sensitivity

Table 2. Comparisation of characteristic values of encapsulated and reference composite elements; pressure range of 100 MPa; room temperature at 23°C ± 2°C; 2.5 V voltage supply

		Without casting (Type 0)	Encapsulated (type 1)	Encapsulated (type 2)	Encapsulated (type 3)
Shore hardness	-	-	A-25	A-45	A-49
Nominal output signal	mV	14.33	14.43	14.05	13.78
Sensitivity	µV/VMPa	57.3	57.7	56.2	55.1
Sensitivity-ratio	%	99.65	100.35	97.74	95.83
Nonlinearity	%	0.53	1.71	1.64	2.2
Hysteresis error	%	0.2	0.99	1.02	1.74
Zero point error	%	0.07	0.15	0.19	0.9

of type 1 is within the tolerance range, too. Thus, the encapsulation with the softest casting of Shore hardness A-25 results in no measurable influence according to the sensitivity. For the worst case, the sensitivity is reduced by 0.2% at maximum in case of the soft casting setup type 1. But the comparison regarding the systematic errors of type 0 and 1 shows a negative interaction for the encapsulated sensors due to higher errors.

The measurement results of type 2 and type 3 show more results in table 2. The sensitivity ratio of 97.7% for type 2 respectively 95.8% for type 4 results in a trend, that the harder the casting compound, the more the sensitivity is reduced. At the same time the systematic errors increase.

On the other hand, the silicone casting compound should not be much softer than the tested soft casting of type 1, because the softer the materials the more errors occur. During handling, connecting with the pressure measurement setup or pressure loading the bond wires have been sheared off for some parts due to too weak mechanical stability.

4. Conclusion and Outlook

The presented measurements with varying castings result on the one hand in best characteristic values for type 1 setup with an encapsulation of Shore hardness A-25. On the other hand, the stronger mechanical stability of the harder silicones is advantageous due to the simpler handling.

Currently the most appropriate option of the three presented castings seems to be type 2. The reduction of sensitivity of about 2% for the encapsulation with Shore hardness A-45 is tolerable, while the systematic errors are of the same value as that of the softer encapsulation.

Initial measurements with the presented experimental setup of type 2 have been carried out successfully at 200 MPa. As a result of recent improvements, measurements with encapsulated setups will soon be possible in the increased pressure range of 500 MPa.

To ensure some better chemical resistivity, there is a diffusion barrier needed. With a high-pressure low-cost packaging in mind, a two-step polymer casting meets the extended durability. For even higher chemical resistivity, a diaphragm made of metal is needed. This could even be electroplated on top of the casting compound.

With presented results, a silicone encapsulation works as a low-cost packaging even for high-pressure sensors.

Acknowledgements

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