euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Measuring setup for compensation of shrinkage induced misalignments of adhesive bondings

Matthias Mohaupt[1], Thomas Bolz[1], Rainer Daum[2]

[1]*Fraunhofer Institute for Applied Optics and Precision Engineering*
[2]*FEI Deutschland GmbH*

Matthias.Mohaupt@iof.fraunhofer.de

Abstract

Adhesive bonding is the major means of fixing mechanical and optical components and systems. However, the shrinkage of adhesives during curing changes their mutual alignment, depending on the thickness of the adhesive layer, the percentual volume shrinkage of the adhesives, the curing temperature, and the shape of the join patch. A concept for shrinkage compensation is the modification of the thickness of the adhesive layer by an offset during initial alignment, as a function of measured shrinkage properties.

The developed measuring setup can characterize shrinkage properties with measuring uncertainties less than 1 µm and allows for discriminating between different reasons of misalignment during curing. It consists of two probes. One is fixed, and the other flexible in three degrees of freedom on an actuator system. Their positions are measured by two independent measuring systems which use customized mirror surfaces as reference planes and detect these by interferometers and capacitive sensors. Materials with low coefficient of thermal expansion minimize potential thermally induced misalignment of the measurement device. The thermal distribution of the setup is stabilized by a cooling system and controlled by temperature sensors.

The results show the measured absolute deviation of adhesive layers in a range of 1-5 µm and the change of the alignment status in three degrees of freedom (adhesive layer thickness, tip and tilt). The concept of offsetting the shrinkage induced misalignment was proven.

Keywords: adhesive bonding, shrinkage compensation, measuring setup

1. Motivation

High precision bonding by adhesives is challenging because of their shrinkage properties. Depending on the adhesive layer thickness and chemical composition the percentual volume shrinkage of an adhesive during curing can reach up to 15 %, and is in the order of microns. The curing regimen, thermal or by radiation, is also important for shrinkage. An alignment status in micron range cannot be kept without the use of special tools or processes. While most manufacturers supply detailed data on volume shrinkage it is not uncommon that properties of the same type of an adhesive differ among batches. Here we compensate the shrinkage induced misalignment of components by offsetting their initial alignment. This strategy relies on knowledge of real shrinkage, as measured on representative components and adhesive layer geometries. Therefore, a respective measuring setup should implement the specific bonding conditions, as are the curing regimen, temperatures, and adhesives. The measuring uncertainty is required to be less than 1 µm at any time of the curing process, which can take up to 24 hours at room temperature.

2. Concept

The concept of shrinkage measurement is to assemble one probe fixed into the measuring device and another probe alignable in three degrees of freedom, so allowing measurement of the deviation of layer thickness, tip and tilt. Two different independent measuring systems were implemented, in order to redundantly monitor the probes during curing. Comparisons of the values as delivered from both systems help identify measurement failure, and provide information on the movement of sensor mounts, part mounts and actuator.

A result of the shrinkage characterization the offset value for the optimized adhesive layer thickness will be calculated and applied during the bonding and alignment process. After curing the adhesive layer will be set to accuracy in the micron range.

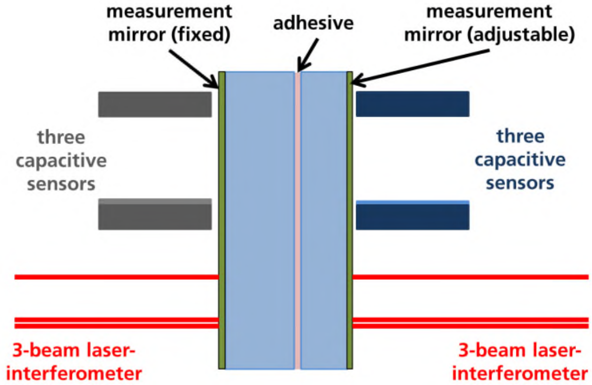

Figure 1. Measuring concept

2.1. Systems

The measuring systems are laser interferometers and capacitive sensors. The capacitive sensors latter have a measuring range of 50 µm, with increment of 2 nm (1). Metallization of the measuring planes of the monitored probes is required, and was performed by sputtering a chromium layer. The same metallization on measuring surfaces with surface planarities of 10 nm acted as mirrors for the interferometer measurements. The measuring uncertainty of the interferometers was 1 µm, as specified in the manufacturer's calibration certificate. Two sets capacitive and interferometer channels of three sensors monitored the movements of the probes from each side. The sensors were able to detect the z-movement as the shrinkage of the adhesive layer thickness, as well as the rotation of tip and tilt degrees of freedom.

2.2. Setup

The measuring setup consists of a base plate made of invar steel with a coefficient of thermal expansion (CTE) of $2*10^{-6}$ K^{-1}. All mechanical parts for mounting the sensors and the probes were made of invar steel, too, in order to minimize thermally induced deformations and position movements of all integrated parts. The temperature of the measuring device was monitored by temperature sensors at different positions. The measuring device was thermally stabilized by a cooling mechanism.

Meeting the measuring uncertainty of the interferometers required environmental stabilisation of humidity and atmospheric pressure (2). This was realized by hermetic sealing of the measuring device like a vacuum chamber. Measurements on rigidly mounted mirrors showed stability of the interferometer signal within 0.1 nm. So the setup guarantees the required measurement stability of less than 1 µm.

2.3. Procedure

The two plane-parallel probes were assembled and pre-aligned outside the measuring device prior to integration. This was done to ensure both proper application of the adhesive with a layer thickness of 50 µm and parallel alignment within less than 5 µm. When probes were integrated into the device one was fixed to a mechanical holder, and the other was flexible on a piezo actuator. The capacitive sensors and the interferometers were aligned perpendicular to the mirror surfaces. The interferometers were set to the initial (zero) measuring value. The capacitive sensors were aligned to the mid of the measuring range (25 µm) to the metalized surfaces. Measurement started as soon as the device had been closed, and ended when the adhesive layer had been finally cured. Measurements were acquired during a time span of 24 hours. For the investigation of different adhesive layer thicknesses and tip-tilt positions the actuator was used for alignment of the moveable part. After curing the bonded probes were removed from the device and inspected.

3. Results

For the evaluation of the setup measurements on fixed mirror substrates were performed. After optimization of the hermetic sealing the stability of both the interferometers and the capacitive sensors were less than 0.5 µm throughout.
The thermal stabilisation was within 1 K. The measuring device showed a good correlation between the thermal drifts and the positional deviations of sensors and probes.

Shrinkage of the adhesive layers was in the range of 1-5 µm, depending on the specific adhesives and the layer thicknesses. Table 1 show the absolute misalignment and the percentage shrinkage of the probes with adhesive layer thicknesses of 50 µm and 100 µm.

Table 1 Adhesive layer deviations after curing

Sample No.	adhesive-shrinkage on optical axis ΔZ	misalignment tip angle δX	misalignment tilt angle δY
Adhesive-thickness 100 µm			
1	2,68 %	97,6 µrad	54,8 µrad
2	2,72 %	23,0 µrad	42,3 µrad
Adhesive-thickness 50 µm			
3	2,60 %	3,10 µrad	77,5 µrad

The ΔZ -position means the deviation of the layer thickness in % - values between the probes, the δX - and δY the tip and tilt variation in µrad. The measured shrinkage values are in the range of <3%.

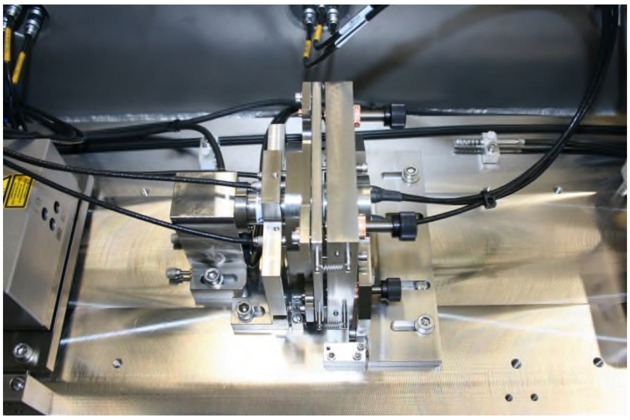

Figure 2. Measuring setup

4. Summary

The developed measuring setup can reliably monitor the shrinkage of adhesive layers during curing, and characterize different adhesives with respect to their shrinkage properties, as a function of probe geometry. So reversely, it allows for full prior compensation of shrinkage induced misalignment. By measuring the shrinkage values of adhesive on a statistic representative number of probes the misalignments of the bonding process will be minimized in future activities. Although very cost and time consuming, the procedure pays off in high precision adhesive bonding with alignment requirements of the adhesive layer thickness in the micron range.

References

[1] Micro-Epsilon Messtechnik GmbH und Co. KG: WAP-Sensorik - Abstandsmessung mit kapazitiven Sensoren, Messen Prüfen Automatisieren, Nr. 9/2016

[2] Pöschel, W.; Dontsov, D. and Manske, E. (2006): Der Geometrie auf der Spur - Hochgenaue Längen- und Winkelmessungen mit Dreistrahl-Interferometern, Laser+Photonik, Nr. 2/2006